PROCEEDINGS

CANADIAN LAND RECLAMATION ASSOCIATION

18th ANNUAL MEETING

1993

LANDSCAPE CHANGE :

OPPORTUNITIES AND NEW APPROACHES

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ACKNOWLEDGEMENTS

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SESSION I: AGGREGATE RECLAMATION

REHABILITATION OF GRAVEL PITS AND QUARRIES FOR BIODIVERSITY

Mark Browning

Ontario Ministry of Natural Resources, Southern Terrestrial Ecosystems Research Section, Science Research and Technology Branch

ABSTRACT

Biological diversity has been defined by the Ontario Wildlife Working Group as "the variety of wildlife species, the genetic variability of each species, and the variety of different ecosystems they form". Aggregate extraction has an important role in maintaining a mix of landscapes, habitats and species. Rehabilitated extraction sites can provide the necessary habitats for unique plant and animal communities and may act as havens for rare or threatened species. In some cases, extraction has led to the expansion of a species range, and the industry is one of the few that is creating new valuable wetland and cliff habitats. Observations of abandoned extraction sites in Ontario demonstrate that biodiversity can be achieved with sometimes dramatic results. Several such sites are described. Information from these sites can be used to develop rehabilitation techniques that will enhance biodiversity at current extraction operations. Landform and waterbody design as well as various planting techniques will be discussed.

Introduction

Biodiversity, or biological diversity, has been defined by the Ontario Wildlife Working Group (1991) as "the variety of wild life species, the genetic variability of each species, and the variety of different ecosystems they form". In the past, few Ontario aggregate sites were deliberately rehabilitated to create biologically diverse wildlife habitat. Typical strategies involved backfilling and uniform seedings.

However, observations of abandoned extraction sites in Ontario and elsewhere, as well as some rehabilitation designs specifically for wildlife from Britain and the U.S. are demonstrating that aggregate extraction has an important role in maintaining a mix of landscapes, habitats and species. Rehabilitated extraction sites can provide the necessary habitats for unique plant and animal communities and may act as havens for rare or threatened species. In some cases extraction has led to the expansion of a species' range, and the industry is one of the few that is creating new valuable wetland and cliff habitats.

In Britain, environmental groups have recognized this potential and will support extraction projects that create good wildlife habitat as an end use. The Royal Society for the Protection of Birds has even published a practical manual entitled "Gravel Pit Restoration for Wildlife" (Andrews and Kinsman 1990).

Examples of Former Extraction Sites in Ontario with High Biodiversity

Observations of abandoned extraction sites in Ontario are beginning to demonstrate that biodiversity can be achieved with sometimes dramatic results. Some examples are given below. This is a new project and each site has only been visited twice in the summer so the species numbers are by no means final.

Kerncliff Limestone Quarry (Burlington)

* approximately 40 years old
* pH: large pond = 8.00 marl = 7.45
* number of vascular plant species = 117
* number of bird species = 45
* number of mammal species = 9
* number of herptile species = 11

There is a good variety of habitats and species for such a small site which is right next to established suburban developments. The area is especially diverse in trees and shrubs (32 species). Breeding bird species include Virginia Rail, Sora Rail and Yellow-billed Cuckoo.

Fletcher Creek Limestone Quarry (Puslinch Tp)

* approximately 45 years old
* pH: groundwater flow = 8.20 marl = 7.40 lower pond = 8.35
* number of vascular plant species = 83
* number of bird species = 47
* number of mammal species = 4
* number of herptile species = 6

Groundwater seepage across the floor of this quarry has resulted in the development of marl deposits supporting a rich variety of sedges. Orchids found growing on this sedge mat include Spiranthes romanzoffiana (Hooded Ladies-tresses) and Liparis loeselii (Twayblade). A snake hibernaculum among the boulders and broken limestone pavement is used by eastern garter snake, northern ribbon snake, northern water snake and eastern milk snake.

CN Gravel Pit (Vespra Tp)

* approximately 15 years old
* number of vascular plant species = 72
* other species not yet inventoried

The predominantly droughty sand and gravel substrates have been naturally colonized by Schizachyrium scoparium (Little Bluestem) a rare Ojibway prairie grass that is native to Ontario. Other plants with prairie affinities here include Elymus canadensis (Canada Wild Rye) and Asclepias tuberosa (Butterfly-weed).

Techniques to Enhance Biodiversity

It is no longer acceptable to wait 30 years for a site to become a valuable wildlife area. Information from abandoned sites such as those described above is being used to develop relatively inexpensive techniques that will enhance biodiversity at current extraction operations. With a carefully planned progressive rehabilitation program a pit or quarry can support a wide variety of species even while extraction is on-going.

Physical (topographic) diversity will lead to biological diversity. Microtopographic variation on slopes and floors can be created by mounding of material and leaving large boulders exposed at the surface. Variation in slope angles and aspects should be strived for, including the presence of some vertical faces (in quarries) which will often support unusual plant and animal groupings. The Ministry of Natural Resources is currently helping to fund an interesting study by Dr. Doug Larson and several graduate students from the University of Guelph. This research is examining the predictability of the plant community that develops on old quarry faces and the similarities between it and the flora of the Niagara Escarpment.

A variety of soil types and overburden types should be used to form the surface on different parts of the site. A fertile topsoil will create rapid plant growth but non-native weed species present in the seed bank will be the dominant growth. It is best to use topsoil in areas that are to be seeded or planted by the operator and use subsoil and waste rock on other portions of the site.

Plants such as white ash, native dogwoods, and strawberry can colonize even a rocky talus quite quickly on their own. This moist sandy silt has been colonized extensively by a variety of sedges and supports unusual species such as the insectivorous Drosera rotundifolia (Round-leaved Sundew).

Steep slopes subject to severe erosion cannot be left for natural succession and should be seeded quickly with a grass/legume mixture. The biology and habitat requirements of different grass species can vary greatly so the choice of ground covers should be made carefully. The Ministry of Natural Resources is currently testing a variety of grass species, including some native ones, on plots set up in different pit and quarry sites. These are being monitored for species survival, growth and rate of natural succession. Some of the commercial grass species can hinder colonization by native plants and may prevent natural succession for many years.

Some preliminary results from one such set of test plots at an active quarry are shown in Figure 1. The mean number of wild plant species colonizing each plot is shown for the commercial grass species which had > 50% ground cover one growing season after sowing. Plots were sown in the spring of 1992 and were assessed in August of 1992 and 1993. The letters used on the X-axis represent the following grass species:

TF = Tall Fescue (Festuca arundinacea), RT = Red Top (Agrostis gigantea), CR = Creeping Red Fescue (Festuca rubra), CB = Canada Blue Grass (Poa compressa), HF = Hard Fescue (Festuca longifolia), BE = Colonial Bent Grass (Agrostis capillaris), N = control plot not seeded.

Species count data were normalized using the square-root transformation (Sokal and Rohlf 1981) prior to analysis by means of a one-way ANOVA for randomized block designs and Tukey's studentized range test. Sown grass treatment had a significant effect on number of colonizing wild species. Species numbers in control plots were significantly higher than in all other treatments (Figure 1). Species numbers in Canada Blue Grass, Hard Fescue, and Bent Grass plots were significantly higher than in Tall Fescue plots.

Tree seedlings should not be planted into dense grass stands where they will be outcompeted for light, water and nutrients. It is better to plant into bare ground, apply herbicides, or use a mulch around seedlings. Mulches can include wood chips, bark, paper sludge, even gravel. A mulch helps to keep moisture in the soil next to the seedling as well as to prevent competing weed growth. Use of some mulches with very high carbon to nitrogen ratios may require initial fertilizer additions.

Mixed tree plantings can aid in weed control where a rapidly growing species acts as a nurse crop for more slowly growing species. Black walnut growth, for example, can be increased by interplanting with black locust which provides competition control, wind protection, and increases soil nitrogen levels with its nitrogen fixing abilities (Von Althen 1990). The Ministry of Natural Resources is currently establishing tree seedling trials on pit and quarry sites to determine the best interplanting combinations.

Surface Water and Waterbody Design

The presence of standing or flowing surface water will greatly increase the biodiversity of a site. As we have seen, groundwater seeps can result in unique habitats and plant communities. Extensive shallow-water areas (less than 1.5 m deep) and seasonally flooded wet areas are very productive and diverse. However, deep water bodies with no shallows, and square basins with no islands, bays or peninsulas to create sheltered water areas are of limited wildlife value.

A good shoreline profile is low-angled with many curves. Part of the rehabilitation plan should include construction of shallow littoral zones for fish nursery areas and gravel shoals for spawning. An accurate estimate of the final water level after rehabilitation is necessary for success but is one of the hardest things to do in a hydrogeological study especially for quarries. If enough material is available to produce a long gentle slope than an accurate estimate becomes less important.

On large water bodies without shelter, wave action will erode shallows and prevent plant establishment. Shallows should be created on the leeward side of shores (consider the direction of the prevailing winds), or be protected by islands, peninsulas and shelterbelts. Large fallen trees at the waters edge provide resting sites for wildlife and feeding and cover areas for fish.

In determining the potential of an extraction site for rehabilitation to fish habitat the water quality, especially variations in temperature and dissolved oxygen content, as well as the seasonal fluctuations in water depth should be considered. Brook trout, for example, have a preferred temperature range of 16 - 18 °C and a minimum requirement of >6 mg/L dissolved oxygen. Largemouth bass on the other hand can survive in water temperatures as high as 29 -32 °C and dissolved oxygen levels as low as 2 mg/L.

If the pond or lake has groundwater as its major source of supply then conditions are probably suitable to support cold water fish species. In other cases, if water levels are stable through the summer, then losses due to evaporation and infiltration are being replaced by groundwater and overland inflows and flushing rates should be sufficient for warm water fish species. In all cases certain areas of the water body must be deep enough to prevent winter kill from lack of oxygen. More details on the requirements of various fish species and the creation of fish habitat are given in Michalski et al. 1987.

A passive end use is desirable on the land surrounding a groundwater fed lake or pond to protect the quality of overland flow entering it. If other land uses are planned than surface water may have to be directed away from the pond using a system of swales.

Some Current Examples of Rehabilitation for Biodiversity

Aggregate extraction sites which are being deliberately rehabilitated for biologically diverse wildlife habitat are just beginning to appear in Ontario. Examples of these include:

Wayside Pit, Williamsburg Twp.

This pit was extracted to produce areas of both deep and shallow water. An uneven bottom was created which will enhance the diversity of aquatic bottom flora and fauna. Shorelines of the pond were made sinuous and islands and peninsulas were included to increase the overall length of the land/water interface. Placement of logs and brush piles at one end will provide good cover for fish and also serve as habitat for aquatic insects on which fish feed. In this instance a good approximation of the final water level was known because of an older wayside pit nearby which had filled with water. After only one growing season cattails and sedges have naturally colonized most of the shoreline. Wildflowers such as Gerardia purpurea (purple gerardia) are present and minnows and frogs can be found in the pond.

Crieff Pit (Puslinch Tp)

This 30 ha gravel pit was inactive for approximately 10 years prior to the removal of gravel and final rehabilitation in 1990. As part of a design by the Hamilton Region Conservation Authority and Dr. Paul Eagles of the University of Waterloo, two groundwater fed ponds with sinuous low profile shorelines and islands were dug. On the upland portion a rough microtopography was created using mounds of surface materials and boulder piles. Some near vertical slopes were left facing in several directions. A variety of materials from fine sand to gravel to bare rock make up the surface substrate. No seeding or plantings were done and revegetation relies on natural colonization. In most areas this strategy is working although

vegetation has not yet established on some of the finer materials which are eroding. On a one day visit this summer 78 vascular plant species and 22 bird species were documented here.

Snyder Flats (Region of Waterloo)

This active gravel pit is being progressively rehabilitated to fish and wildlife habitat. Located on a bend of the Grand River it is a large (100 ha) project which will help restore linkages between the river and its floodplain. A cold water pond maintained only by ground water, with maximum depths of 5m has been created. The total surface area has been kept small and banks on two sides fall steeply into deep water to help maintain the cool water temperatures. Shade trees will be planted at the top of these banks. A shallow littoral zone on the east shoreline will allow colonization by aquatic plants. This pond will be stocked with native cold water species. Two floodplain pools are being created which will be maintained by controlled flow from the Grand River. Constructed with bays and islands, these will provide a variety of habitats for wildlife. Gravel is still being extracted to create a warm water pond. This pond will be connected to the floodplain pools and so be maintained by both surface water and groundwater. The larger surface area of this pond will help maintain the average water temperature above 20 °C. This pond will serve as a spawning area for northern pike, largemouth and smallmouth bass from the river.

There is a great potential for former aggregate sites to support biologically diverse communities. As old rehabilitation techniques are modified and new ones developed it is hoped that carefully prepared site-specific designs will lead to a greater number of pit and quarry sites being rehabilitated for wildlife habitat.

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AGGREGATES IN BRAMPTON: EXTRACTION & REHABILITATION IN THE BRAMPTON ESKER AREA

Sherry Yundt

S.E. Yundt & Associates Ltd.

ABSTRACT

The extraction of aggregate (sand, gravel and crushed stone) in urban landscapes present challenges related to hydrogeology, ecology, land use and environmental impacts (noise, dust and truck traffic). The City of Brampton and the aggregate producers have faced the challenges created by urban extraction a succeeded in creating some outstanding rehabilitated sites.

At least 80 million tonnes of high quality sand and gravel have been extracted from the Brampton Esker area. The building of Toronto's infrastructure has been greatly assisted by aggregates sites close to construction projects such as the Gardiner Expressway, Ontario Place, the Queen Elizabeth Way, Pearson International Airport, early stages of the Toronto subway system and many other roads, streets and highways not only in the City of Brampton, but throughout the Region of Peel and the Greater Toronto Area.

Don Gordon, Commissioner of Parks and Recreation, City of Brampton, says it is "unequalled" to have the aggregate industry in a municipality because after the aggregate is extracted the land can be rehabilitated to network of parks and recreation areas, such as those in the Brampton Esker area. With more planning for rehabilitating pits and quarries, as required under the Aggregate Resources Act, the land can be returned to some exceptional land uses of benefit to all the public.

Aggregate extraction takes place to meet demand for sand, gravel and crushed stone created by growing and redeveloping urban areas. When extraction of aggregate occurs as close as possible to the markets, there are many benefits,

- *lower transportation costs;*
- *less pollution (shorter distance to market);*
- *less energy used in truck haulage;*
- *less damage to highways and other roads; and*
- *less truck traffic.*

Aggregate extraction is an interim land sue. Because the deposit was an esker, the City of Brampton has been able to create ecological linkages between sites and create a linked trail system. The land is borrowed for extractive use and returned to parkland and residential areas. The green spaces created are of value to all the residents of the area.

Fourteen sand and gravel operations have been identified in the City of Brampton and ten of these have been fully rehabilitated. Specific rehabilitation of these ten sites are described. Sand and gravel has been extracted since the turn of the century in Brampton and will continue in the year 2000 at the one remaining license site, Franceschini Bros. Aggregates Ltd.

Other municipalities with large numbers or growing numbers of aggregate operations can learn by studying what has occurred in the City of Brampton.

Background

The extraction of aggregate (sand, gravel and crushed stone) in urban landscapes presents special issues and concerns to be overcome. Some of the challenges relate to hydrogeology, ecology, land use, environmental impacts (noise, dust and truck traffic), etcetera.[1] The City of Brampton and the aggregate producers have faced the challenges created by urban extraction and succeeded in creating some outstanding rehabilitated sites. The Brampton Esker area was unusable for development before sand and gravel was extracted. By extracting aggregate resources, consumer demand was fulfilled and parks, recreational and residential land uses were created.

At least 80 million tonnes of high quality sand and gravel have been extracted from the Brampton Esker area. The building of Toronto's infrastructure has been greatly assisted by aggregate sites close to construction projects such as--the Gardiner Expressway, Ontario Place, the Queen Elizabeth Way, Pearson International Airport, early stages of the Toronto subway system and many other roads, streets and highways not only in the City of Brampton, but throughout the Region of Peel and the Greater Toronto Area.

The Parks and Recreation Master Plan for the City of Brampton sets out the criteria for parks in the City as follows, "Each area of the City should have access to parks that perform a variety of functions. Some may be passive parkland areas that provide beauty, buffering, relief from urban land form, as well as an area to walk, rest, think and picnic."

"Other areas need to provide active parkland space for sports functions ranging from children's play equipment areas to major, lighted baseball diamonds and sports complexes, as well as possibly performing many of the functions of a passive park."[2]

The City of Brampton has achieved its Master Plan objectives, by creating an exceptional park and open space system, after many areas were depleted of sand and gravel. The City of Brampton is growing rapidly, with the 1976 population at 103,445, the 1986 population increasing by over 80% to 188,415 and the 1996 population estimated at 261,000 (Figure 1). This rapid growth requires millions of tonnes of aggregate. The availability of water areas, resulting from extraction of aggregate below the water table, in the form of various lakes, has been a major asset in rehabilitation. Some exceptional opportunities in land rehabilitation around lakes are illustrated by Professor's Lake, the Parr Lakes North and South and Major Oaks

Don Gordon, Commissioner of Parks and Recreation, City of Brampton, says it is "unequalled" to have the aggregate industry in a municipality because after the aggregate is extracted the land can be rehabilitated to a network of parks and recreational areas, such as those in the Brampton Esker area. With more planning for rehabilitating pits and quarries, as required under the Aggregate Resources Act, the land can be returned to some exceptional land uses of benefit to all the public.

The Aggregate Resources Act which came into effect in 1990 provides for enhanced rehabilitation by requiring the following,

- revised detailed site plans;
- more municipal involvement in site review;
- conformity to zoning bylaws;
- detailed consideration of surrounding land uses;
- retention of topsoil, subsoil and overburden;

---

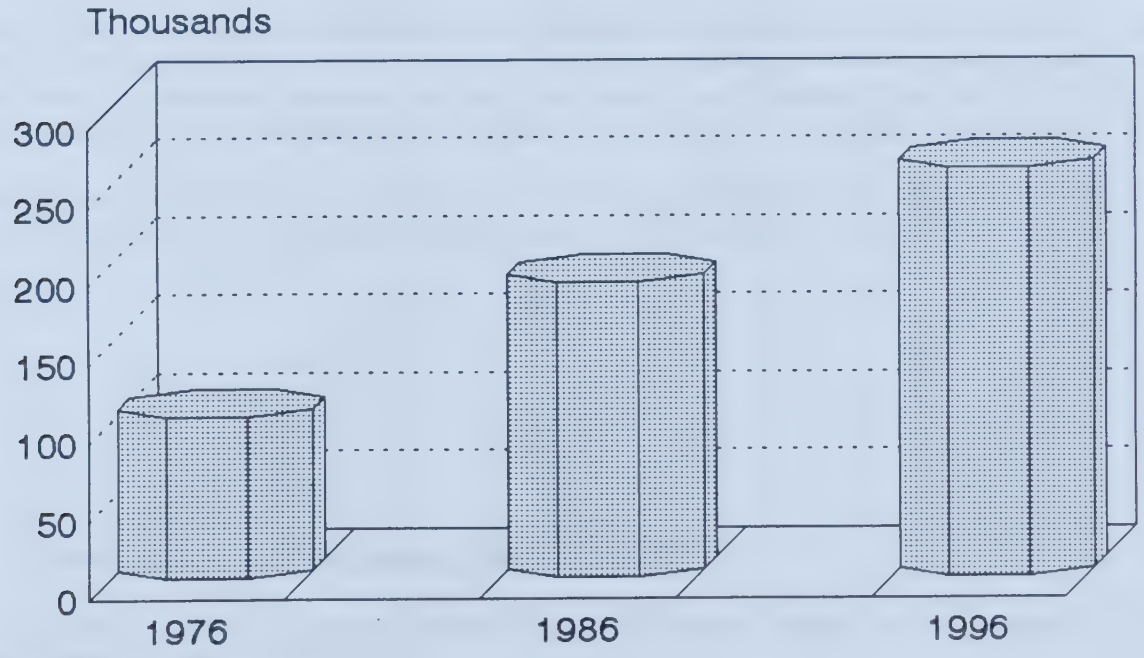
[1] Jaakson, R., "Recreation Design Alternatives for a Disturbed Urban Landform," Landscape Planning, 1981, pp. 31-68.

[2] City of Brampton, Parks and Recreation Master Plan Background Report, September 1990.

POPULATION

CITY OF BRAMPTON

FIGURE 1



- a fund for rehabilitating abandoned pits and quarries;
- an 8¢ per tonne rehabilitation security; and
- mandatory progressive rehabilitation.[3]

Geology

"An esker is a long narrow winding ridge of sand and gravel laid down as a stream deposit by glacial meltwater flowing through crevasses and channels in or beneath a stagnant ice-sheet...Owing to the fact that in many places the eskers were the last glacial material deposited, these prominent sand and gravel ridges running across the country form a good source of sand and gravel."[4]

The Brampton esker is located about 15 miles (25km) west of Toronto in the City of Brampton. The esker is believed to be of late Wisconsinan age (20,000 years ago) and was probably deposited when the Ontario ice lobe was undergoing ablation. The Brampton esker trends west-northwest and is approximately 4.5 miles (7km) long and varies from 0.1 miles (0.2km) to 0.4 miles (0.6km) wide.[5] The esker consists of variable deposits of coarse, medium, and fine gravel with stratified sand, silt and clays.[6]

History of Operations

In 1918, Ledoux[7] described four operations in the Brampton Esker area. Hewitt and Karrow[8] have detailed descriptions of nine sand and gravel pits operating in the Brampton Esker in 1963. Sand and gravel has been extracted from the Brampton Esker since the turn of the century. In all likelihood sand and gravel will still be produced from the one remaining licensed pit operated by Franceschini Bros. Aggregates Ltd. after the year 2000.

Fourteen sand and gravel operations have been identified in the City of Brampton. Ten of these sites have now been fully rehabilitated and two are in proposal stages. Details of these operations are given in Figures 2 and 4.

---

[3] Statutes of Ontario, 1989, Aggregate Resources Act, 1989.

[4] Hewitt, D.F. and P.F. Karrow, Sand and Gravel in Southern Ontario. Ontario Department of Mines, Industrial Mineral Report 11, 1963, p. 23.

[5] Saunderson. Houston C, "Sedimentology of the Brampton Esker and Its Associated Deposits: An Empirical Test of Theory," Glacial Fluvial and Glacial Lacustrine Sedimentation. ed. by Alan V. Jopling and Barrie C. McDonald, 1975, pp. 155-176.

[6] Hewitt and Karrow, p. 59.

[7] Ledoux, A. Sand and Gravel in Ontario. Ontario Bureau of Mines, 1918, P. 79.

[8] Hewitt, D.F. and P.F. Karrow, Sand and Gravel in Southern Ontario. Ontario Department of Mines, Industrial Mineral Report 11, 1963, p. 59.

FIGURE 2 CITY OF BRAMPTON

AGGREGATE EXTRACTION SITES AND USE IN 1993

SITE #	AGGREGATE COMPANY	SITE NAME	USE IN 1993
1	Peel Sand and Gravel Ltd.	1st Line	Richvale Park, Sacred Heart, Terry Fox & Robert H. Lagerquist Sr. Schools
2	Armstrong Brothers Co. Ltd.	Donnelly	Donnelly Park, Barr Cres. & Esker Drive
3	Livingston Sand & Gravel	---	Maplehurst, Reynier & Astorville Parks
4	Armstrong Brothers Co. Ltd.	Bovaird	Proposed Development
5	Franceschini Bros. Construction Ltd.	Cooper	Graham Kaneff Proposed Development
6	Franceschini Bros. Construction Ltd.	Brampton	Active Licensed Operation
7	Salisbury Sand and Gravel Ltd.	---	Major Oaks Park
8	J.C. Duff Ltd.	Clarkson	Bramalea Ltd. Community Park
9	Kenmore Building Materials Ltd.	---	Bramalea Ltd. Community Park
10	Mel Ackroyd	---	La France Park
11	Gormley Sand and Gravel Ltd.	Parr	Parr Lake North & South & Vodden Street
12	Armstrong Brothers Co. Ltd.	Chassels	Norton Place Park
13	Standard Aggregates Inc.	Malton	Professor's Lake
14	John Ackroyd (Bramalea Ltd.)	---	Idle

Mineral Resource Production

Figure 3 shows the mineral resource production, as collected by the Ministry of Natural Resources, from 1974 to 1992. Mineral resource production in Figure 3 consists of both shale quarries and sand and gravel pits. After 1983, production is combined for the Cities and Brampton and Mississauga, for reasons of confidentiality.

In 1974, their were 4 (Brampton only) mineral resource licences producing a total of 1,958,834 tonnes of material. By 1992, their were 7 (Brampton & Mississauga) mineral resources licences producing a total of 259,277 tonnes.

MINERAL RESOURCE PRODUCTION

CITY OF BRAMPTON ('000 TONNES)

FIGURE 3

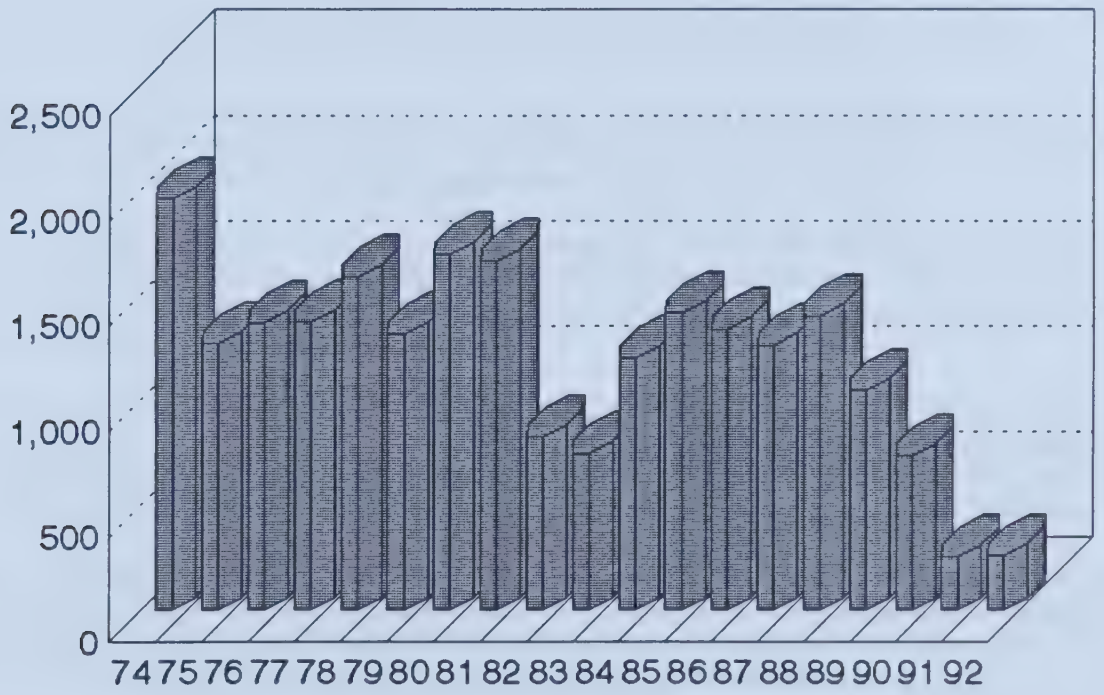


Figure 3, graphically indicates how production is directly related to the economy. The recessions that started in 1982 and 1990, clearly stand out with less mineral resources required in a time of general economic recession. Since 1990 the number of active licensed mineral resource operations has decreased to 3 (Brampton & Mississauga), as the resources are depleting.

Rehabilitation

PEEL SAND AND GRAVEL LTD. (1) This is an engineered landfill site. Approximately 60 feet (18.3 metres) of fill was placed in the site between 1972-1977. This site was opened in 1964 and aggregate was last extracted in 1972. The area currently has residential areas, Richvale Park and Sacred Heart, Terry Fox and Robert H. Lagerquist Sr. Schools, in the area that was previously extracted for aggregate. Richvale Park contains two major baseball diamonds, two major soccer pitches, two tennis courts, walkways, picnic areas, a toboggan run and both senior and junior playgrounds. R.H. Lagerquist Sr. School has two minor baseball diamonds and a basketball court. Terry Fox School has two minor soccer pitches and a basketball court.

ARMSTRONG BROTHERS CO. LTD. (2) This is the Armstrong Donnelly Site which was opened in 1938, was depleted of aggregate in 1977. Over 5 million tonnes of aggregate were removed from the pit and it was partially filled. This is now Donnelly Park surrounded by residences on Barr Crescent and Esker Drive. The park is planted with trees and shrubs and has a junior playground for children. Many lighted walkways cross the park.

LIVINGSTON SAND AND GRAVEL (3) The last extraction of aggregate from this site occurred in the mid 1960's and the site was partially filled. Today the area is a beautiful residential area between Kennedy Road and Richvale Drive. The area has three small neighbourhood parks--Maplehurst, Astorville and Reynier.

ARMSTRONG BROTHERS CO. LTD. (4) The Armstrong Bovaird site was opened in the early 1930's and depleted of aggregate in 1988. It is estimated that between 15-20 million tonnes was removed from the property over its 35 year life. The site is still licensed under the Aggregate Resources Act, awaiting rehabilitation to housing, parkland and trail development.

FRANCESCHINI BROTHERS CONSTRUCTION LTD. (5) The Cooper site was opened by Industrial Sand and Gravel in 1955 and later operated by J.C. Duff Ltd. It was taken over by Franceschini Bros. Construction Ltd. in 1961. Aggregate was extracted from this site between 1955 and 1988 (33 years). The property is now owned by Graham and Kaneff who propose to develop the site which is currently being engineered, filled, sloped and graded.

FRANCESCHINI BROTHERS CONSTRUCTION LTD. (6) This site is an active licensed operation under the Aggregate Resources Act. The licence is held by The Warren Paving & Materials Group Limited and operated by Franceschini Bros. Aggregates Ltd. The site was opened in 1958 and will operate for at least another 15 years. It is the only active licensed sand and gravel site remaining in the City of Brampton.

SALISBURY SAND AND GRAVEL LTD. (7) Many aggregate producers operated this site in the 1950's and 1960's. Production of aggregate stopped in 1971, the site was partially filled and rehabilitated to Major Oaks Park. The park contains a lake, several walkways and it is landscaped with trees and shrubs. The park is enjoyed by many local residents for outdoor recreation. The lake is stocked with trout and is surrounded by a major soccer pitch and a toboggan hill.

J.C. DUFF LTD. (8) & KENMORE BUILDING MATERIALS LTD. (9) Industrial Sand and Gravel originally opened these two properties and several other aggregate producers operated them periodically. Site 8 (Figure 1) was opened in 1954 and later operated by J.C. Duff Ltd. and site 9 was later operated by Armstrong Brothers Co. Ltd. These sites are currently owned by Bramalea Ltd. and are known as Bramalea Ltd. Community Park. Large parts of these sites were filled. Many sports activities take place at this site including soccer and baseball. The park includes a senior playground and a large parking lot surrounded by grassed areas and gardens. Many trees and shrubs landscape the site.

FIGURE 4 BRAMPTON Scale 1:35,000

1	PEEL SAND & GRAVEL LTD
2	ARMSTRONG BROTHERS CO LTD
3	LIVINGSTON SAND & GRAVEL
4	ARMSTRONG BROTHERS CO LTD
5	FRANCESCHINI BROTHERS CONSTRUCTION LTD
6	FRANCESCHINI BROTHERS CONSTRUCTION LTD
7	SALISBURY SAND AND GRAVEL LTD
8	J.C. DUFF LTD
9	KENMORE BUILDING MATERIALS LTD
10	MEL ACKROYD
11	GORMLEY SAND AND GRAVEL LTD
12	ARMSTRONG BROTHERS CO. LTD
13	STANDARD AGGREGATES INC
14	JOHN ACKROYD (BRAMALEA LTD)

MEL ACKROYD (10) The site was owned by Mel Ackroyd, opened by J.C. Duff Ltd. in 1955 and later operated Armstrong Brothers Co. Ltd. ABC Readymix and ABC Precast used the site as a yard. The site was filled and rehabilitated to La France Park. This is a small neighbourhood park with a senior playground and a minor soccer pitch.

GORMLEY SAND AND GRAVEL LTD. (11) This site was opened originally before 1918 and Armstrong Brothers Co. Ltd. reopened it in the 1930's and left the site in 1953. It is estimated that Armstrong Brothers Co. Ltd. removed between 10-15 million tonnes from this site. The Parr pits were operated by Gormley Sand and Gravel Ltd. between 1960 and 1971. Approximately 1.5 million tonnes of aggregate were extracted by Gormley Sand and Gravel Ltd. over 11 years. The site has two appealing lakes with subdivisions backing on them. These lakes are called Parr Lake North and South and are situated north and south of Vodden Street between Highway 410 and Dixie Road. Lighted walkways run along the west shore of the lakes and the parks are well landscaped and provide welcome open spaces.

ARMSTRONG BROTHERS CO. LTD. (12) The Chassels site was originally opened before 1918 and reopened by J.C. Duff Ltd. in 1949 and last operated as a gravel pit in 1966. Armstrong Brothers Co. Ltd. removed 200,000 tonnes of aggregate for a subdivision project. It is now the site of an attractive lake and recreational area surrounded by apartment buildings, condominiums and businesses. The area, known as Norton Place Park, is in a mature state of rehabilitation with many large trees and shrubs surrounding the lake. Park benches are available for the enjoyment of park users.

STANDARD AGGREGATES INC. (13) In 1989, Professor's Lake was awarded the Aggregate Producers' Association of Ontario (APAO) prestigious Bronze Plaque. Standard Aggregate Inc. was the last aggregate company to operate the site. Ledoux[9] in his 1918 report entitled "Sand and Gravel in Ontario" indicates this site was open in 1918. The site was reopened as a gravel pit in 1954 by Co-Op Trucking. It was subsequently operated by Commercial Sand and Gravel and in 1960 Consolidated Sand and Gravel (now Standard Aggregates Inc.) took over the pit. Peel Sand and Gravel Ltd. opened and operated a 100 acre (40 hectare) pit in the west half of the aggregate deposit. Consolidated Sand and Gravel eventually purchased the Peel Sand and Gravel Ltd. property.[10] This site was partially filled. The operation ceased in 1973. During its 19 year life this outwash deposit supplied an estimated 20 million tonnes of sand and gravel to the Toronto area.

The APAO Bronze Plaque was awarded to the City of Brampton and Standard Aggregates Inc. for the 203 acre (82 hectare) combined residential and recreational/parkland complex established in this former gravel pit. The main feature of the Professor's Lake complex is a 65 acre (26 hectare), spring fed lake. This lake was produced by extracting sand and gravel below the water table. The lake is used extensively for sailing, windsurfing, fishing and canoeing. Other recreational pursuits include watersliding, tennis, playgrounds and ice skating in the winter. Professor's Lake is surrounded by residential housing with the Professor's Lake Recreation Centre on the south shore. The Recreation Centre was built in 1982 including a boat house, beach, picnic area, miniature golf, food concessions and meeting rooms.[11]

Professor's Lake is classified as special, city wide parkland in the City of Brampton, Parks and Recreation Master Plan. This is an outstanding example of sequential land use. Don Gordon, Commissioner of Parks and Recreation for the City of Brampton calls Professor's Lake a "showcase" of extraction followed by rehabilitation. He says

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[9] Ledoux, A. Sand and Gravel in Ontario. Ontario Bureau of Mines, 1918, p. 79.

[10] Canadian Aggregates, "APAO Bronze Plaque Given to Brampton's Professor's Lake Site," August-September, 1989, pp. 6-7.

[11] Ibid, p. 7.

"people love water" and Professor's Lake is a significant water resource away from Lake Ontario. The lake is surrounded by lighted walkways and is it attractively encompassed by gardens, trees and shrubs.

JOHN ACKROYD (BRAMALEA LTD.) (14) This site was operated by several companies including J.C. Duff Ltd. and it ceased operation in the mid 1960's. Aggregate from this site was used to build Highway 400. The land is now owned by Bramalea Ltd. and it awaits development.

Conclusions

Aggregate extraction takes place to meet demand for sand, gravel and crushed stone created by growing and redeveloping urban areas. When extraction of aggregate occurs as close as possible to the markets, there are many benefits,

- lower transportation costs;
- less pollution (shorter distance to market);
- less energy used in truck haulage;
- less damage to highways and other roads; and
- less truck traffic.

Benefits such as those listed above have arisen because of aggregate extraction in the City of Brampton. Aggregate extraction is an interim land use. Because the deposit was an esker, the City of Brampton has been able to create ecological linkages between sites and create a linked trail system. The land is borrowed for extractive use and returned to parkland and residential areas. The green spaces created are of value to all the residents of the area.

Other municipalities with large numbers or growing numbers of aggregate operations can learn by studying what has occurred in the City of Brampton.

The lessons learned from the extraction and rehabilitation that has happened in the City of Brampton include,

1. The more planning of extraction and rehabilitation, the better the final results will be.

2. Extraction should be designed to maximize the final grades and landform required for the rehabilitation.

3. All fill placed in extraction sites, including types and amounts, should be carefully monitored as it progresses.

4. Co-operation and good will between the municipality and the aggregate producer is critical at all stages of aggregate extraction and rehabilitation.

NATURAL AGGREGATE RESOURCES IN RIVER CORRIDORS: ECONOMIC BENEFITS AND ENVIRONMENTAL OPPORTUNITIES

Don Stewart

Planning Initiatives Ltd.

ABSTRACT

The purpose of this paper is to present a series of case studies illustration how new approaches to aggregate extraction within river corridors can and are being undertaken with specific rehabilitation design intended to achieve both environmental gains for the immediate site and surrounding community, and for additional economic benefits to both aggregate operators and other parties. Planning Initiatives Ltd. has been involved in a number of such projects along the Grand River and Upper Thames River which are designed to achieve just such benefits by capitalizing on specific opportunities.

In the past, aggregate resources were extracted, in some cases, with little thought for the potential impacts on the environment. The result was often a landscape where the environment was given little recognition in the decision making process for rehabilitation. However, since the 1950's, the rehabilitation of pits and quarries has advanced, both in terms of scientific research, and legislation and regulations. Many rehabilitated sites today are unrecognizable as former pits and quarries. Today the Aggregate Resources Act and associated regulations make specific provisions for progressive rehabilitation, and have recognized rehabilitation as a crucial factor in aggregate resource development. Rehabilitation requirements and objectives are constantly evolving and with this, people are becoming aware not only of the additional requirements, but also of new opportunities which may exist to not only re-create pre-extraction uses, but to enhance the post-extraction environments.

Because the larger urban areas of southern Ontario consume a large proportion of the aggregates extracted and because of the high cost of transporting such aggregates, it is important and cost effective to obtain aggregates from as close to the urban areas as possible. Planning Initiatives Ltd. is promoting and committed to the concept of the "Urban Resource Rescue" for aggregates found in near-urban areas, in order to ensure they can be extracted prior to being sterilized because of other urban development. In some cases, major aggregate deposits are located within river floodplains, in or near these larger urban centres. Such is the case in both the Kitchener and London areas.

The paper will highlight specific case studies where innovative aggregate extraction and rehabilitation operations are being utilized to create the setting for post extractive uses which will improve the environment and level of community amenities in many ways including environmental enhancement, recreational improvements, residential development, and other uses. Revenues from such operations and joint ventures can also assist municipalities and public sector agencies during uncertain economic times.

As these types of examples become more common, the range and level of techniques for rehabilitation sites and improving the environment will increase and provide further economic and environmental opportunities.

SLIDE #	DESCRIPTION
1,2	Introduction - Planning Initiatives Ltd. and Topic
3	Rivers and Associated Wetlands are a source of water and life, a highly valued landscape continually under pressure from a history of settlement and land use. The natural resources contained in River Corridors provide economic and environmental opportunities.
4	Environmental gain is possible. Former unproductive, agricultural land or unused lowland areas in the floodplain can produce enhanced wetland environments, water bodies (cold/warm water), aquatic and terrestrial habitat as well as provide educational opportunities in an area adjacent to major urban centres.
5	Valuable economic gravel resources are often found in River Corridors. Extraction provides revenues to the municipalities in which the pit occurs, the aggregate producer has satisfied and fulfilled consumer demand for his product and can wisely utilize the available resources within the area.
6	Are aggregate extraction and protection/enhancement of natural and environmental areas incompatible land uses? A number of project Planning Initiatives Ltd. has worked on demonstrate clearly that they need not be incompatible.
7	Urban Resource Rescue Program refers to a strategy and philosophy utilized by Planning Initiatives Ltd. to ensure that aggregate resources, especially in near urban areas are protected or "rescued" before other urban development and activity result in the sterilization or loss of these valuable resources can be extracted.
8	In the Grand River Corridor, a significant transformation has occurred over the past 100 years with the settlement of the area. The Grand River has lost much of the original riverine habitat which once existed in the floodplain areas, through such activities as farming, clearing the land, drainage, urban expansion, etc.). Historically, these areas provided refuge, a food source and breeding areas for many species of mammals, waterfowl and fish. It is estimated that only 35% of the original wetlands in the Grand River watershed exist today. The loss of these areas reduces the ecological diversity and stability of the ecosystem. Are these areas now lost to us? The Grand River Corridor also is the source of major aggregate resources in a major urban area. Within this corridor there are a number of examples of completed, ongoing and proposed projects which illustrate how aggregate extraction and effective reclamation of the land can enhance such areas.

The following discussion will examine the methods by which aggregate extraction, with a well designed operational and rehabilitated reclamation plan can assist in recreation of these natural habitat areas, resulting in both economic and environmental benefits.

Bloomingdale Pit and Snyder Flats Project

9	A joint venture, Preston Sand and Gravel Limited and the Grand River Conservation Authority, has provided the opportunity to reconstruct these natural areas. Location - east side of the Grand River in the Township of Woolwich, and comprises 96 hectares. Close proximity to the urban area of Kitchener-Waterloo, but predominantly rural in nature.

10 Prior to gravel extraction, the floodplain area was low productivity agricultural land, subject to periodic flooding. Original site plan showed the rehabilitation of the site to agriculture.

1987 discovery of valuable aggregate resources below the water table in the floodplain provided an opportunity to re-evaluate final land use opportunities, with economic and environmental benefits.

11 Overview of the subject area during the early extraction period, showing the processing area in the foreground, a couple of the ponds under excavation and the urban area of Kitchener/Waterloo across the other side of the Grand River in the background.

12-14 Through well planned and innovative gravel extraction, the process of regenerating to an environment similar to that which might have existed in this watershed prior to settlement in the area is feasible.

Extraction of a valuable natural resource (aggregate materials) will leave behind a series of diverse habitats and breeding areas for both aquatic and terrestrial species through the creation of a number of floodplain pools and a cold water pond.

Final product will be a valuable site for public education and enjoyment, as well as providing an area for fish and wildlife in a highly urbanized setting.

15,16 Preston Sand and Gravel worked closely with the Grand River Conservation Authority on this project. Public participation included mailing of pamphlets to local residents, invitations to the open house, a number of press releases and interviews, and a questionnaire to residents regarding the project.

River Oaks, Kiwanis, and South Staton

17-21 Immediately south of the Snyder Flats/Bloomingdale Area are several other existing, proposed,and potential areas along the river where aggregate resources can and are being extracted or rescued in plans to result in a variety of ultimate final land uses. The River Oaks residential development represents an exclusive residential area. To the east of the River Oaks residential development (also a former aggregate operation) is Kiwanis Park and the South Staton area. Both areas are underlain by large reserves of gravel resources and located in the floodplain area.

22 Moving further south along the Grand River near the eastern border of Kitchener, there are a number of existing and proposed projects which will continue the "green" corridor along the river.

Grand River Park

23,24 Grand River Park, a project to provide a recreation area for the citizens of Kitchener now is in the approval stages. The proponent is the City of Kitchener.

25,26 Extraction of gravel in a floodplain area, with the royalties paid to the City will be used to create a recreation park with a marsh area, as well as canoeing and fishing areas for the citizens of Kitchener.

27-28 Terrestrial and Aquatic Habitat will be created by selective shaping of the pit floor and by creating habitat niches such as islands and bays.

Bickle Natural Area

30-35 Bickle site is located just south of the Grand River Park project, across Highway 7. It has regenerated naturally to provide two natural ponds suitable for fishing, nature observation, picnicking and hiking.

Summary

36,37 Planning for Better Times Calls for a New Vision of Rehabilitation Planning that provides:

- Economic benefits and environmental gains
- Creative and innovative rehabilitation land forms and uses which:
  - are cost effective to the producer
  - enhance environmental objectives of an area
  - meet the recreational/residential opportunities of the area

With innovative initiatives and the creation of well designed plans, we can utilize existing and future aggregate resources in such a way as to get both economic and environmental gain.

Putnam Tract Class 1 Wetland

38-42 This last example shows another illustration of how we can utilize existing operations not only to protect valuable environmental areas **(39)**, but in fact to enhance them, in this case a Class 1 Wetland along the Upper Thames River Corridor. Natural revegetation has already started and we are assisting it in order to expand the wetland. In doing so, we can enhance the environmental opportunities so that in the future, we will have other areas such as this ideal setting for a hiking trail along a riverside berm which has naturally revegetated itself over the last 35 years.

NATURALIZING QUARRY SITES IN SOUTHERN ONTARIO

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ABSTRACT

Two approaches to renaturalizing quarry sites located in southern Ontario are discussed. The first approach, which was applied at the Walker Brothers quarry in Thorold, involves the use of nursery stock planted in cells. As the planting mature, they should begin to spread and intergrade with each other to form a dynamic, diverse and self-sustaining vegetation community. The second approach, which was applied at the Dufferin Aggregates Milton quarry, involves the use of forest soil as the source of vegetation stock. The soil, which was stripped as part of the on-going extraction operation, provides a large quantity of seeds, rhizomes and stolons. These native species should be sufficient to provide a dynamic, evolving plant community. Both of these sites will be monitored over the long term to determine changes in the vegetation community composition, influence on colonizing plant species and use by wildlife. The first year's results of the monitoring program are discussed.

Introduction

Quarry rehabilitation invariably involves the establishment of vegetation regardless of the planned afteruse. Rehabilitation specifically for wildlife habitat entails the establishment of a vegetation community that is diverse, composed mainly of species native to the area, self-sustaining both in the short and long term and that will progress towards a climax community which is familiar to the area. Several techniques exist for the establishment of such a vegetation community, each with their own merits and disadvantages (Table 1).

Table 1.
Vegetation Establishment Techniques and their Relative Merits and Disadvantages

	Planting of Nursery Stock	Soil Seed Bank	Transplantation of Existing Plants	Direct Seeding of Native Woody and Herbaceous Plants	Natural Colonization with no Intervention	Notes
1. Level of control over species established	medium to high	low	medium to high	high	low	natural succession always has final word as to species
2. Relative cost	high	low	medium to high	medium	low	
3. Level of expertise required	medium	medium	high to medium	high	low	
4. Time of establishment of target community	medium to fast	medium	medium	medium	slow	

Table 1.
Vegetation Establishment Techniques and their Relative Merits and Disadvantages

	Planting of Nursery Stock	Soil Seed Bank	Transplantation of Existing Plants	Direct Seeding of Native Woody and Herbaceous Plants	Natural Colonization with no Intervention	Notes
5. Species availability problems	yes	no	yes	yes	no	
6. Level of maintenance required	high	low	high	medium	low	

This paper examines the preliminary results of the use of soil seed banks and the planting of nursery stock as vegetation establishment techniques at two sites: the Milton Quarry (Dufferin Aggregates) and the Thorold Quarry (Walker Brothers Quarries Limited). The results are preliminary since they represent the first set of data collected for what is to be a long-term (several years) monitoring program of vegetation establishment and succession.

Milton Quarry (Dufferin Aggregates)

Milton Quarry is established on the Niagara Escarpment. Prior to the quarry the site was forested with the dominant species being sugar maple (*Acer saccharum*), white ash (*Fraxinus americana*), and red oak (*Quercus rubra*).

Slopes along the western edge of the quarry were created in 1991 using a topsoil and subsoil mixture at 3:1 to 2:1 slopes. Topsoil is native to the quarry site and has been applied directly following stripping. Soil originates from a variety of forest types including cedar lowland. Seedlings of staghorn sumac, autumn olive (*Eleagnus commutata*) and white spruce (*Picea glauca*) were planted on these slopes following soil application.

Observation of the slope in the summer of 1992 revealed that a diverse vegetation community comprised of various exotic and native forbs, grasses, sedges and volunteer staghorn sumac had developed amongst the planted seedlings. Other slopes that had been created using pond fines with no application of topsoil were virtually bare after several years except for the occasional coltsfoot (*Tussilago farfara*). Also, slopes that had not received an application of topsoil exhibited signs of significant erosion whereas the slope that had been created from the topsoil/subsoil mixture, had no observable erosion. Dufferin Aggregates' Property and Resource Manager and staff from Ecological Services for Planning Ltd. (ESP) agreed that there would be some value in studying the dynamics of the vegetation on the slopes over the long term to determine if simply spreading forest topsoil would be a sufficient effort to initiate the development of a diverse and productive native plant community. The aim of the study is to examine the succession of the vegetation community over the long term using annual measurements of percent cover by species.

Methods

To measure the percent cover of the various species along the slope, ESP established four randomly placed quadrats, each measuring 30m in length. The ends of the transects were marked with wooden stakes which are to remain in place permanently. A point quadrat frame was used to record vegetation cover at one metre intervals along each transect. The frame was placed perpendicular to the transect line and a plumb bob was dropped at six points along

the frame, each 20 cm apart. The species of the first plant touched by the plumb bob was recorded for a total of 720 records along the four transects. Percent cover for each species represents the total number of times that the plumb bob touched a given species over the total number of plumb bob drops (i.e. 720). All records were taken on July 18, 1993 and will be recorded in subsequent years at approximately this date.

Results and Discussions

Coltsfoot (*Tussilago farfara*) has by far the highest percent cover (68.1%) followed by bare ground (8.9%), alfalfa (*Medicago sativa* (4.7%), staghorn sumac (*Rhus typhina*) (4.0%), red raspberry (*Rubus idaeus*) (2.4%), and boneset (*Eupatorium perfoliatum*) (2.2%) (Table 2). Other species indicated on Table 2 have a very low percent cover. Of the 27 species recorded, approximately 22% are exotic whereas 78% are native. Few woody species were recorded and it was not possible to differentiate between those staghorn sumacs that had been planted from those that had arisen from rhizomes or seeds present in the seed bank. It is known, however, that not all of the sumacs present on the slope were planted. Other species present on the slope but not recorded include swamp milkweed (*Asclepias incarnata*), choke cherry (*Prunus virginiana*), columbine (*Aquilegia canadensis*), black-eyed susan (*Rudbeckia hirta*) and oxeye daisy (*Chrysanthemum leucanthemum*). American hazel (*Corylus americana*) and poplar (*Populus* sp.) seedlings were also present but only on the quarry floor adjacent to the base of the slope.

Table 2.
Percent Cover of Species Recorded on Slope at Milton Quarry

Scientific Name	Common Name	Percent Cover	Status
Tussilago farfara	Coltsfoot	68.1	E
Bare Ground	Bare Ground	8.9	
Medicago sativa	Alfalfa	4.7	E
Rhus typhina	Staghorn Sumac	4.0	N
Rubus idaeus	Red Raspberry	2.4	N
Eupatorium perfoliatum	Boneset	2.2	N
Glyceria striata	Fowl Manna Grass	1.3	N
Solidago canadensis	Canada Goldenrod	1.0	N
Rubus occidentalis	Black Raspberry	0.9	N
Carex stipata	Sedge	0.7	N
Equisetum arvense	Field Horsetail	0.5	N
Rubus odoratus	Flowering Raspberry	0.5	N
Aster puniceus	Purple-stemmed Aster	0.4	N
Clematis virginiana	Virgin's - bower	0.4	N
Eupatorium maculatum	Spotted Joe-pye Weed	0.4	N

Table 2.

Percent Cover of Species Recorded on Slope at Milton Quarry

Scientific Name	Common Name	Percent Cover	Status
Carex retrorsa	Sedge	0.3	N
Cornus sericea	Red-osier Dogwood	0.3	N
Euthamia graminifolia	Grass-leaved Goldenrod	0.3	N
Muhlenbergia sp.	Muhly Grass	0.3	N
Poa palustris	Fowl Manna Grass	0.3	N
Potentilla norvegica	Strawberry weed	0.3	E
Bromus inermis	Smooth Brome	0.1	E
Daucus carota	Wild Carrot	0.1	E
Lycopus uniflorus	Northern Water-horehound	0.1	N
Picea glauca	White Spruce	0.1	N
Ribes americanum	Wild Black Currant	0.1	N
Solanum dulcamara	Bittersweet Nightshade	0.1	E
Vitis riparia	Riverbank Grape	0.1	N

E - exotic
N - native

The relative absence of woody species was unanticipated. Other studies have shown early colonization by native woody and herbaceous species from the seed bank for forest topsoil used in site reclamation (Farmer *et al.*, 1982; Johnson and West, 1989; and Wade, 1989). The soil seed bank is at least partly responsible for succession in old fields (Egler, 1954), and it is important in recovery of forest stands after disturbance through supplying species that are important in the early stages of secondary succession (Livingston and Allessio, 1968). The relative absence of woody plants in this study may be due to competition by the herbaceous vegetation. American hazel and poplar seedlings were found growing at the bottom of the slope in the absence of herbaceous species.

Since the soil was used immediately after stripping, soil storage time should not have contributed to the low numbers of woody plants. Results from other studies have shown an exponential decrease in seed numbers in soil following a disturbance (Roberts and Dankins, 1967; Roberts and Feast, 1973; Hargis and Redente, 1984). Other studies have shown the opposite; the number of viable seeds in samples from a one-year-old to two-year-old topsoil stockpiles exceeded the number in samples from freshly stockpiled topsoil (Iverson and Wali, 1982 and Johnson and West, 1989). The latter two studies were only conducted using topsoil stockpiles of a maximum of two years old and it is unknown what the viability of seeds is in soils stored for longer periods.

Data collected from future years will help to elucidate the vegetation dynamics on the slope. Further studies which ESP hopes to conduct at the Milton Quarry would investigate such factors as:

- soil storage time;
- soil provenance;
- supplemental fertilization; and
- supplemental seeding with native seeds.

Thorold Quarry (Walker Brother Quarries Limited)

In early 1993, Walker Brothers Quarries Limited was granted a licence to expand their current quarry operations. Conditions of the licence, as expressed in the site plan, included the planting of numerous areas prior to site operation in order to provide screening and/or wildlife habitat. ESP was retained to develop the landscape design and planting plan and to provide supervision during the landscaping work to ensure that the plans were followed as intended. Although these plantings are not established as part of the quarry rehabilitation work *per se*, their design and intended purpose are analogous to that of rehabilitation plantings. A series of plantings were also established along a section of the existing quarry to increase biotic diversity.

Methods

Site lines from adjacent roads and residences were determined using a topographical plan and field verification. Plantings were then designed that would provide adequate screening at the required time and that would also have other attributes such as wildlife habitat and native vegetation community development. Plantings were designed in cells measuring approximately 10m x 10m, 10m x 50m and 20m x 50m. Trees and larger stock were planted in the centre of the cell and shrubs on the outer edges to simulate the natural appearance of small forested pockets. Table 3 shows the species that were used in the cells. It is hypothesized that the cells would spread in time and join together to form larger forested bands. Conifers within the cells were laid out in such a way as to provide year round screening as well as wildlife cover. Prior to planting, the cells were mulched with wood chips to a depth of 10 cm. The mulch was added to reduce weed growth, maintain soil moisture and reduce the incidence of rodent damage. Spot herbicide application was done in the first year after planting in those cells that showed a relatively high level of weed infestation.

Table 3.
Species Planted at the Thorold Quarry (Walker Brothers Quarries Limited)

Scientific Names	Common Names	Notes
Shrubs		
Aronia arbutifolia	Red Chokeberry	Although an exotic to the area, it was used due to its salt tolerance
Clethra alnifolia	Sweet Pepperbush	" "
Cornus racemosa	Grey Dogwood	
Cornus sericea	Red-osier Dogwood	
Rhus typhina	Staghorn Sumac	

Table 3.
Species Planted at the Thorold Quarry (Walker Brothers Quarries Limited)

Scientific Names	Common Names	Notes
Salix discolor	Pussy Willow	
Sambucus canadensis	Elderberry	
Viburnum dentatum	Arrow-wood Viburnum	
Viburnum lentago	Nannyberry	
Viburnum trilobum	Cranberrybush Viburnum	
Trees		
Acer rubrum	Red Maple	
Acer saccharum	Sugar Maple	
Acer saccharinum	Silver Maple	
Amelanchier canadensis	Serviceberry	
Betula papyrifera	White Birch	
Celtis occidentalis	Hackberry	
Fraxinus americana	White Ash	
Gleditsia triacanthos	Honeylocust	
Larix laricina	Tamarack	
Picea glauca	White Spruce	
Pinus strobus	White Pine	> 50% mortality of seedlings; planted late
Populus tremuloides	Trembling Aspen	20% mortality; perhaps due to herbicide drift
Prunus virginiana	Choke Cherry	
Robinia pseudoacacia	Black Locust	Although an exotic, it was used due to its salt tolerance
Quercus rubra	Red Oak	
Thuja occidentalis	Eastern White Cedar	
Tsuga canadensis	Eastern Hemlock	

To date, cells that have been established include those along a portion of the edge of the existing quarry (1992), those along a major screening berm (1993), and those at the intersection of two main roads (1993). Additional cells will be added over the next year to complete the pre-operational landscaping requirements.

Results and Discussion

Mortality of the planted stock was inspected during the months following planting and was found to be higher for some species than others. Aspen, eastern white cedar, and white pine (seedlings) had mortality levels of approximately 20% to 50% while that for other species was lower. Mortality may have been due to poor stock that could not cope with the relatively harsh conditions of the site. Although the site was prepared by plowing and harrowing, large clumps of the clay soils were still evident after planting. Even with occasional watering and initial fertilization, the conditions for plant growth are still less than favourable due to the difficulty in providing good soil tilth and due to plant desiccation on the wind-exposed sites. Survival rates of most of the plants, however, are considered adequate.

Monitoring over the next years will reveal which species survive best and exhibit the fastest growth and which species begin to colonize the cells through wind-dispersed and bird-dispersed seeds. Robinson *et al.* (1992) found that after 14 years only half of the original 190 plants planted as part of a landfill reclamation effort had survived. An additional 752 trees and shrubs had colonized the plantation and its perimeter, as well as 2955 stems of vines. However, over 95% of woody plants that had colonized were not progeny of the plant cohort, but instead belonged to 18 invading species, mostly native, bird-dispersed, and associated with intermediate stages of secondary plant succession. Based on their findings, Robinson *et al.* (1992) suggest that plants used in rehabilitation work be selected not only in terms of their survival and growth but also based on the following criteria:

- high and quickly realized reproduction capacity;
- attractiveness to seed dispersers; and
- relatively rapid turnover to permit continued successional sequence.

Plantings at the Thorold Quarry will also be assessed on the basis of the above criteria.

Results from Robinson *et al.* (1992) appear to suggest that the initial plantings do not so much provide the biological source for colonization and vegetation spread but rather provide physical and biological attributes by which natural plant dispersal, colonization and succession can take place. Plantings at the Thorold Quarry differ from those in the Robinson *et al.* (1992) study in that planting cells were used at the Thorold Quarry whereas individual trees and shrubs were planted in the other. It was noticed that one year after planting, some of the staghorn sumacs were spreading vegetatively. Time will reveal whether planting cells, by simulating some of the characteristics of natural vegetation groupings, can also provide the source by which the plantings spread and develop into diverse, self-sustaining ecosystems.

Conclusion

First-year results of two long-term vegetation establishment projects indicate that while providing a highly diverse flora, use of the soil seed bank at Milton Quarry has failed to provide adequate amounts of woody species. These woody species are required if the vegetation community is to develop into an early successional, mid-successional and finally a climax forest community. Further monitoring results will reveal the dynamics of this community and may lead to insight into the importance of soil seed bank versus colonization from wind and animal-dispersed seeds as the factor determining species composition.

Initial results of vegetation establishment at the Thorold Quarry using planted nursery stock indicate good survival rate of the plants. Future monitoring results will show whether the plantings are responsible for any spread in woody vegetation or whether other sources such as wind and animal dispersion are responsible.

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SESSION II: RECLAMATION INITIATIVES

NATIVE BUSINESS DEVELOPMENT THROUGH RECLAMATION

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ABSTRACT

NOVA Corporation of Alberta is a widely held, shareholder-owned company operating internationally from headquarters in Calgary, Alberta. NOVA builds its future principally on pipelines and the manufacturing and marketing of chemicals produced primarily from Alberta natural resources. As part of their philosophy, the Corporation supports a unique policy to encourage the Native community to participate in the growth and development of the Canadian economy and to ensure Native people are involved in all aspects of the Corporation's operations.

NOVA's Reclamation program is designed to effectively stabilize the right-of-way as soon as possible after construction, re-establishing native vegetation where appropriate, enhancing fish and wildlife habitat where possible, and to meet the requirements of regulatory agencies and landowners. In the past, native contractors have been used primarily where seeding was required within the forested Green Zone of the province. In recent years, this involvement has been expanded to include the agricultural White Zone, averaging 38% of the total work over the past eight years. In 1991, the Environmental Management Department dedicated one person as a liaison between NOVA and the aboriginal contractors in an effort to improve communication and information exchange. Pre-bid meetings and workshops were initiated to improve the aboriginal contractors' understanding of NOVA's reclamation requirements, and to assist them in effectively bidding on projects. The reclamation program within the Alberta Gas Transmission Division of NOVA has been a useful vehicle for aboriginal contractors to diversify, improve the quality of their work, improve their competitive salary and develop viable businesses.

Introduction

NOVA is a public company owned by shareholders which operates from headquarters in Calgary, Alberta. NOVA serves its customers by producing, marketing and transporting sweet natural gas, and by developing chemicals and plastics to meet customer needs.

Alberta Gas Transmission Division (AGTD) is a division of NOVA Corporation of Alberta. AGTD plans, designs and constructs natural gas pipelines in Alberta and then operates and maintains them. AGTD measures natural gas for its customers, ensures quality control and moves the gas through the pipeline network.

AGTD's pipeline network is the main system for transporting natural gas in Alberta and carries over 75% of all marketed Canadian gas each year. Gas is delivered through more than 18 000 kilometres of pipeline to points in the province and to the borders for export outside the province.

As part of their philosophy, the Corporation supports a unique policy to encourage the Native community to participate in the growth and development of the Canadian economy and to ensure Native people are involved in all aspects of the Corporation's operations. In 1992 NOVA was named 'Employer of the Year' by the Native Employment Services Association.

This paper will review NOVA's commitment to Native development and focus on the contribution of AGTD's Reclamation Program to that corporate policy.

Nova's Commitment to Native Development

NOVA is committed to a pro-active approach to Native development by assisting Native people in becoming self-sufficient participants in the Canadian economy. To meet this commitment, the corporation has established a series of development initiatives. There are two key factors supporting Native initiatives. First, there is an identified need for employment opportunities in Native communities and second, Native leaders have demonstrated a keen desire to assume control of their affairs.

The development initiatives based on the key factors mentioned above are as follows:

1. Certain types of work are reserved for Native contractors such as clearing facility rights-of-way,
2. Where practical, units are broken into contracts, which smaller Native businesses can undertake,
3. Identifying interested and capable Native businesses, ensuring they are included in the bidding process, that they understand that bidding process and the terms of the contract,
4. Waiving bonding requirements in many cases,
5. Supplying contract liaison and other support services,
6. Paying invoices from Native businesses promptly to avoid compromising their financial stability.

Reclamation Program Contributions

The Reclamation Program within the Alberta Gas Transmission Division of NOVA has been one of the vehicles in support of Native contractors. By NOVA definition, a Native contractor is one which is at least 51% Native owned. The program has assisted Native contractors in developing viable businesses through identification of diversification opportunities, developing high quality work, improving their competitive ability. Native contractors have traditionally been hired to seed pipeline rights-of-way within the forested areas of Alberta. Recently, this involvement has been expanded to include reclamation activities in our agricultural zones. Over the past eight years Native contractors have done 38% of the total work.

NOVA's Reclamation Program is designed to effectively stabilize the right-of-way as soon as possible after construction, re-establish native vegetation where appropriate, avoide introduction of noxious weeds, enhance fish and wildlife habitat where possible and meet the requirements of regulatory agencies and landowners. Contracts are awarded based on past performance, bid information, and work distribution. Bid price is an important factor, as NOVA is responsible to its customers for expenditures, but it is not the only discerning factor in many cases.

The use of Native contractors to implement reclamation plans has been an important part of the reclamation program. In the past, Native contractors have been used primarily where broadcast seeding was required within the forested zone of the province. In recent years this involvement has been expanded to include the agricultural zone and has averaged 38% of the total work over the past eight years. In the mid-1980's, reclamation projects were primarily in the forested zone, this resulted in higher contract expenditures for Native contractors. In 1990, Native contractors accounted for only 12% of the total reclamation contract expenditures. The lower value in 1990 was due to the majority of pipeline construction and subsequent reclamation efforts being in the dry rangeland southeastern areas of the province. These site conditions necessitated the use of specialized techniques and equipment, which were not available from Native contractors on our bidders list.

In 1991, the Environmental Management Department dedicated one person as a liaison between NOVA and the Native contractors in an effort to improve communication and information exchange. Efforts have been focused on Native contractors attempting to develop a business that will be competitive. This effort assists communities

economically and allows NOVA to complete necessary work. An additional benefit is improved community relations. Designating one coordinator to this role resulted in streamlined gathering and organization of project specific information, more effective information transfer and more detailed bid information.

During initial community visits by NOVA representatives prior to construction, information packages are distributed. The increased efforts by the Reclamation Program resulted in more accurate details of potential reclamation contracts and clarified project requirements in these information packages at this early stage. Contractors were provided suitable lead time to meet bidding eligibility requirements, such as insurance coverage, equipment and manpower.

Recent bioengineering initiatives in the Reclamation Program have successfully used Native contractor crews to collect and store suitable cuttings, apply materials to structures and complete final seeding. This initiative has realized a genuine interest on the part of these crews to identify the most suitable species to use for cuttings and to take pride in the final product. In particular, one 1993 project on NOVA's Bear Canyon Lateral resulted in the combined effort where design and implementation were developed co-operatively by a NOVA representative and a Native contractor. The resulting product successfully applied the design skills of NOVA with the implementation skills of the contractor. Bioengineering applications allow the contractors to diversify their knowledge and skills without requiring large investments in new equipment. This support is encouraging in the development of this new initiative for NOVA to stabilize slopes with 'soft' bioengineered structures.

Pre-bid meetings and workshops were initiated to improve the Native contractors' understanding of NOVA's reclamation requirements and to assist them in effectively bidding on projects. Equipment requirements, calibration, material staging, site access, manpower, safety requirements, and any other pertinent information was reviewed at each meeting. Some logistical and organizational problems were encountered but the overall attendance by contractors has been 71%. Contractor response to these meetings is favourable. New contractors agree they would have been totally unprepared to bid accurately without these meetings. Experienced contractors also claim to have a better understanding of NOVA's requirements. Pre-bid meetings also provide a forum for informal discussion of concerns and opinions. As a result of these pre-bid meetings, we have noted a higher awareness of work requirements upon arrival at the job site and increased ability to interpret alignment sheets, as well as an increased attention to safety.

Benefits

NOVA

The most obvious benefit to NOVA is the value of the completed work. Constructing, operating and maintaining the system of over 18,000 km of pipeline and 44 compressor stations requires efficient use of manpower and equipment. Much of the gas transmission system is located in areas where qualified Native contractors are readily available thereby permitting faster and more economic mobilization.

NOVA's visible commitment to Native development allows for smoother recruitment of Native contractors. By honouring a commitment to support development in the Native communities, the company is more attractive as an employer with a genuine interest in current issues. This characteristic of NOVA provides an open avenue for Natives to work with the company. Thus, NOVA progresses in its initiative to increase its support to the Native community.

A partnership with Native communities is fundamental to maintenance and expansion of the gas transmission system. The location of many of NOVA's customers require transport of gas across lands held by Natives. Access must be negotiated by all parties. Trust must be established between the negotiating parties.

Reclamation Program

Benefits of developing Native business extend into the Reclamation Program. Of primary benefit is the increased supply and diversity of equipment. As the Reclamation Program keeps pace with the demands of NOVA's transmission system, a broad and diverse supply of reliable equipment and contractors is vital. The more remote sites, commonly with extremely wet ground conditions, require specialized equipment for implementation which local contractors can supply. Native contractors have geographically broadened the base of qualified contractors.

These groups have also increased our knowledge of local conditions. Many sites have seasonal access and are subject to atypical climates. The local knowledge is an important factor in designing appropriate seed mixes and implementation methods.

Native Contractors

NOVA's efforts to provide opportunities for Native contractors to diversify prepares them to bid on contracts for other companies. The increased experience and broadened skills are marketable to other potential employers. In order for these businesses to be viable, there must be a broad client base.

Traditional work in broadcast seeding has been expanded into three other primary areas of expertise. The reclamation program has developed a bioengineering component over the past 3 years. Work required has been almost exclusively awarded to Native contractors. As this field grows, these contractors will have the experience to supply these specific skills on a competitive basis in a field relatively new to Alberta. Recently, efforts have resulted in assigning drill seeding work to Native contractors as well. This diversifies the services they can offer. The option to purchase the additional equipment provides an avenue to re-invest earnings in their business increasing their asset base. As the scope of the reclamation program grows to include minor earthwork, another door is opened for Native contractor involvement. Over the past year we have contracted the services of Native crews to operate heavy equipment to complete necessary re-contouring to stabilize and re-establish drainage on specific projects.

Experience has shown that our Native contractors are investing earnings in equipment upgrades. As the season progresses, new and improved equipment is available for contract work. This supports the programs' efforts to provide the opportunity for contractors to develop viable and competitive businesses.

Feedback from the Native contractors has also shown that their credibility in the industry has improved. NOVA is a well respected company with high standards to be met by its contractors. According to our Native contractors, successful completion of a contract with NOVA is an important asset to their marketability to other companies.

Challenges

NOVA

A challenge to be addressed as part of the corporate initiatives is to encourage Native students to continue into higher education in order to prepare them to compete in industry and business. As the economy provides less job openings, competition for the available positions increases. NOVA initiated a Summer Education Program in 1986 in which the company sponsors 2 Native university students to visit Alberta schools with high aboriginal student populations to present role models, assist in career planning and promote the 'stay in school' message. Since 1986, 6500 Native high school students have participated in the program.

The changing economy also creates a need for diversification. NOVA can support Native business development by promoting avenues for diversification to provide more goods and services to industry. A broader base of

available incomes is a realistic way to survive the economic fluctuations.

Reclamation Program

One challenge for the Reclamation Program is management of Native and non-Native contracts in agreement with the corporate policy of Native development. Non-Native contractors often have difficulty accepting this policy. The concern arises when work is awarded to Native contractors exclusively. Qualified non-Native contractors meeting other considerations such as proximity to the work-site, competitive prices and available equipment, are not invited to bid if a qualified Native contractor is available.

A second challenge is diversifying Native contractor skills without developing a dependency on NOVA for work. We must be sure to develop abilities that can be marketed to other potential employers. Advising contractors on how to expand their business is difficult to do without leaving the impression that NOVA will provide enough work in the future to make the investment worthwhile. We have an interest in improving our qualified contractor base, but the commitment to developing Native business reaches beyond the needs of NOVA to other companies.

The third challenge applies to all our reclamation contractors, Native and non-Native. To improve the efficiency of our reclamation program, we need to head towards 'minimal supervision' of our contractors. The volume of work created in constructing and operating a pipeline system the size of NOVA's, requires carrying out many activities concurrently. While new reclamation is being implemented, previous work must be evaluated, monitored and any necessary remedial action undertaken. If contractors can continue working without constant supervision, it allows NOVA staff the opportunity to address these other activities in the area.

Conclusion

NOVA has a strong commitment to participate in and encourage the development of Native communities and businesses. This policy is reflected in the objectives and direction of company programs. In order to successfully carry out the Reclamation Program and complete the significant volume of work created by NOVA's gas transmission system expansion within the expected timeframe, it is vital to build and maintain a solid base of qualified and reliable contractors. By directing attention to the development of genuinely interested Native contractors, this base has been expanded and strengthened.

LA VALEUR PAYSAGERE:
UNE PLUS VALUE DE LA REHABILITATION DE SITE

THE DYNAMICS OF LAND RECLAMATION AS A CATALYST FOR LANDSCAPE SHAPING

Marie-Claude Robert et Jean Trottier
presented by Marie-Claude Robert

ABSTRACT

Le present essai propose que tout effort de rehabilitation de site implique de facto la creation d'un paysage. Tout d'abord, nous developperons cette approche pour la presentation d'un cadre methodologique concu pour la mise en oeuvre de plans de rehabilitation.

Dans us deuxieme temps, la demostration de la demarch formelle de creation de paysage est illustree par l'application d'exemples quebecois de pratiques qui expriment et soutiennent la dynamique de rehabilitation de sites.

L'implantation d'un Centre de service Hydro-Quebec a la centrale Brisay (Baie James) servira de cas type.

SELECTION OF NATIVE LEGUME SPECIES FOR RECLAMATION

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ABSTRACT

Natural habitat disturbances are increasing on the eastern slopes of the Rocky Mountains. At present, there is little choice for plant material to use in reclaiming these disturbances since many available grasses and legumes are not adapted to survive or reproduce in the harsh environment at high elevations. The introduction of adapted agronomic plants is a concern because these are often persistent and invasive; they hinder natural succession and can replace indigenous species in natural areas.

In 1990 Wild Rose Consulting Inc. and Alberta Environment Centre began a four year project to collect, evaluate, select, and multiply native legume species for use in reclamation seed mixtures. Fourteen legumes were collected from the mountains and grown in nursery plots in Vegreville. Data concerning establishment, growth and development, yield, and germination were recorded. These data were used to make preliminary selections of five legumes that have potential for use in reclamation seed mixtures. Final selection(s) will be made following one more year of data collection, and these will be tested at several mine sites in the mountains and foothills of Alberta.

Alpine milkvetch appears to have the best potential of the fourteen species studied. It survived well, grew vigorously, spread to cover relatively large areas, and produced large quantities of viable seed. It also emerged well in seeding trials. Other species that have some potential include purple milkvetch, reflexed locoweed, yellow locoweed, and showy locoweed.

Reclamation and revegetation of the numerous, large coal mine disturbances in the mountains and foothills of Alberta is a problem since there are few adapted plant species or varieties available for use in these areas.

Native plants are recommended for reclamation of these sites for several reasons;

i. they are adapted to the sites,
ii. they provide wildlife habitat,
iii. they are less persistent and invasive than some of the agronomic species, and
iv. they create a more natural looking landscape (since these sites are highly visible to tourists).

In 1990, Wild Rose Consulting, Inc. in collaboration with Alberta Environmental Centre began a program to collect, evaluate, select, and multiply native legumes for use in reclamation of high elevation sites. This project was funded by the Reclamation Research Technical Advisory Committee and Canadian Parks Service.

In 1990 and 1991 seeds of native legumes were collected at 34 sites in seven locations (Grande Cache, Jasper National Park, Cadomin-Cardinal River, Banff National Park, Kananaskis, Crowsnest Pass, and Waterton National Park) in the mountains and foothills of Alberta. Species which were collected include *Astragalus alpinus* (alpine milkvetch), *A. americanus* (American milkvetch), *A. vexilliflexus* (purple milkvetch), *Hedysarum alpinum* (alpine sweetbroom), *H. boreale* (northern sweetbroom), *H. sulphurescens* (yellow sweetbroom), *Lupinus nootkatensis* (Nootka lupin), *L. sericeus* (perennial lupin), *Oxytropis cusickii* (alpine locoweed), *O. deflexa* (reflexed locoweed), *O. monticola* (late yellow locoweed), *O. sericea* (early yellow locoweed), *O. splendens* (showy locoweed), and *O. viscida* (viscid locoweed).

Evaluation of species was carried out at a nursery located in Vegreville, Alberta approximately 100 km east of Edmonton. It was assumed that since these species were collected in the mountains and foothills they would be adapted to high elevation sites therefore evaluation was based on agronomic characters: establishment, survival, growth and development, and seed yield of these collections in a nursery.

Seedlings were grown in the winter in the greenhouse and placed in the field nursery in the spring and early summer. Primary evaluation criteria were: survival, vigour, seed yield, and germination of harvested seeds. Other considerations included growth habit (as related to the potential for mechanical harvest), and phenology (as related to harvest time). Data were collected in the first and second growing seasons.

Survival after two growing seasons (one winter) was over 95% for *Astragalus alpinus* and *Oxytropis cusickii*. *Astragalus americanus* had such poor survival in the first growing season that it was dropped form the program. High mortality was recorded for *Lupinus sericeus* over the first winter. *Astragalus alpinus* was the most vigourous species. *Lupinus sericeus*, *Hedysarum alpinum*, and *H. sulphurescens* were the least vigourous. Few plants produced seeds in the first season. In the second season, *Oxytropis deflexa* and *O. monticola* produced over 8000 seeds per plant. The three *Hedysarum* species along with *Oxytropis cusickii*, and *Lupinus sericeus* produced less than 100 seeds per plant. Germination of harvested seeds was excellent (98-100% after 30 days) for all species except *L. sericeus*. Germination of seeds of the latter species was significantly less than other species but in a separate study we found that if larger seeds were selected germination could be improved.

Based on results obtained over two growing seasons, legumes were assigned a rank order as follows:

Astragalus alpinus
Astragalus vexilliflexus
Oxytropis monticola
Oxytropis deflexa
Oxytropis splendens
Oxytropis viscida
Hedysarum boreale
Oxytropis cusickii
Hedysarum sulphurescens
Hedysarum alpinum
Oxytropis sericea
Lupinus sericeus
Astragalus americanus (dropped from program)
Lupinus nootkatensis (unranked due to insufficient data)

Astragalus alpinus is the species that looks most promising to date; it had good survival over two growing seasons, and produced vigourous plants that provide good ground cover. Seed was produced in both years. The seed stalks, however, were low growing and may present some problems for mechanical harvest.

Astragalus vexilliflexus had good survival and vigour and its prostrate growth provides good cover for controlling erosion. Seeds, however, were produced under the prostrate branches making harvest difficult and labour intensive.

Oxytropis monticola had high seed yield and particularly good seed production. Seeds were easily harvested since they were produced in capsules on stiff, erect stalks. An observed second flowering period may result in two harvests each year. Although this species is ubiquitous in Alberta, it does not spread vegetatively to cover large areas.

Seed increase plots were established using transplants in the first year and seeds were harvested annually. In 1992 a plot was seeded with six species for the purpose of multiplying seeds. *Astragalus alpinus* established well and produced small amounts of seed in the first year, and large amounts of seed in the second. *Oxytropis monticola*

and *O. splendens* did not establish as well as the *Astragalus* but did produce seeds in the second season. *Oxytropis deflexa, Hedysarum alpinum*, and *Lupinus nootkatensis* did not establish to any extent. Further tests are required to determine appropriate seeding rates.

Data for the third year are being collected at the field nursery in 1993 and following analysis of these data, final selections will be made. We hope to release the first species' in the spring of 1994 and have seed commercially available as early as 1995.

Laboratory and greenhouse studies have been designed to determine the effectiveness of various arctic and alpine rhizobia on establishment and development of the legume species selected. This study will begin this winter. Further work is planned in testing the selected legumes on various types of disturbances in the eastern slopes of the Rocky Mountains. Trials will be established at coal mine sites beginning in 1994 and selections will be included in a program to compare native seed mixtures with agronomic mixes now being used in forested areas of the mountains and foothills.

USING WASTE WOOD CHIPS TO REHABILITATE LANDFILL SITES

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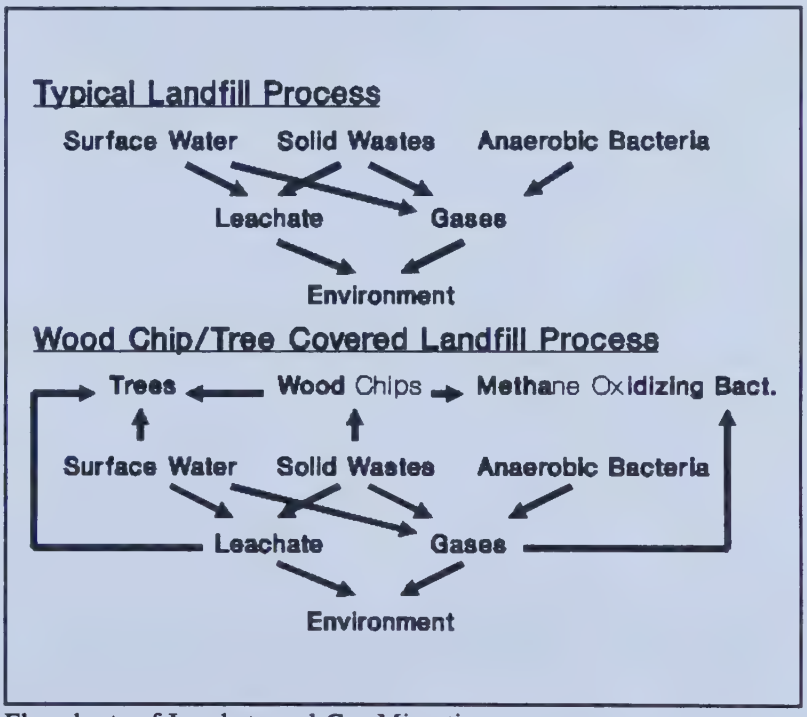
ABSTRACT

Results from the first three years of a ten year study, on the utilization of urban waste wood chips as a mulch and soil aggregate for tree establishment, are presented here. Tree growth trials on a closed landfill site have indicated that waste wood chips (hereafter also referred to as 'mulch') offered a better growing environment through the reduction of mortality and die-back and an increase in shoot and root development. The ultimate aim of this project is to suggest a better method in landfill management through the reduction of wood wastes in the solid waste stream, abatement and redirection of landfill leachate, and an active rehabilitation effort.

Right: Flowcharts indicate how wood wastes can be diverted from the solid waste stream and promote biological activity on an otherwise devoid site.



Flowcharts of Leachate and Gas Migration

Introduction

Waste wood has long been one of the main contributors to the ever increasing demand placed upon our landfills. W.C.I. Wood Conversion Inc., a company dealing with waste wood in the Region of Peel, hypothesized that this waste wood could be processed into wood chips for re-use rather than absorbed by our overburdened landfills.

Landfill sites have long been ascribed to have only a passive use after their closure. They are usually left in a state of open pasture. Reforestation attempts have been made, but mortality of young seedlings is usually found to be quite high.

A project was developed by W.C.I. Wood Conversion Inc., in co-operation with the Regional Municipality of Peel, to determine if waste wood chips (source: pallets, construction wood, tree clippings, etc.), when used as a mulch, could help increase the survival rate of tree plantings. The project was initiated on February 22, 1990 on a landfill site closed since 1980.

Twelve thousand tonnes of waste wood chips were spread on the Chinguacousy Landfill site in the Spring of 1990. That Summer, a preliminary test plantation was established. Results were shown to be very favourable and urged on the planting of some further 16,500 trees. The project results, so far, suggest that processing waste wood into

chips, and applying it as a site preparation for tree establishment, would effectively reduce waste and accelerate landfill rehabilitation after closure.

Aeration of the soil is one of the major concerns for the Chinguacousy site. Aeration is impeded in heavy compacted clay parent material, particularly under wet conditions. With the added stress of CO_2 (Carbon dioxide) and CH_4 (Methane) development from beneath, oxygen availability will be handicapped. In clay soils, percolation of water into the soil and soil aeration are favoured by aggregated soil particles rather than by a plastic structure or cemented layers of hardpans (U.S.D.A., 1990). Therefore discing wood chips (source of aggregate soil particles) into the clay cap will assist in aeration, while retaining most of the mulches advantages.

As far as the Chingaucousy Landfill site is concerned:

The major goals of this project are:

1) Development of Landfill Management and Rehabilitation
2) Development of Tree Establishment Methods

Other goals of this project are:

3) Promotion of Public Education and Recreation
4) Promotion of Wildlife Diversity
5) Timber Biomass Production

The project is currently concentrating its efforts on proper site preparation (i.e. the first two goals).

Experiment and Results

This project, so far, consists of four experimental components. These experimental components are:

- Preliminary Test Plantation (1990)
- Soil/Wood Chip Interactions (1991)
- Austree Plantation (1992)
- Planting Operation (1993)

Preliminary Test Plantation (1990)

A 234-tree preliminary test plantation was established in 1990. The plantation species included Carolina poplar (*Populus canadensis 'Eugenei'*), green ash (*Fraxinus pennsylvanica*), white spruce (*Picea glauca*), and Austrian pine (*Pinus nigra*). Trees were planted in one five treatments (1- Control/Grassed, 2- 5cm thick mulch, 3- mulch plus nitrogen, 4- tilled soil plus mulch, and 5- tilled soil plus mulch and nitrogen). The plantation sought to demonstrate general trends, and so the treatments were applied in five adjacent blocks each containing 6 individuals * 4 tree species (border row trees excluded).

The hardwoods surpassed the conifers both in survival and growth rate. The overall rankings of the species were poplar, green ash, Austrian pine, followed by white spruce. Due to the calcareous nature of the clay cap, it is not surprising that the hardwoods fared better than the conifers did. Carolina poplar responded well to the mulch and fertilizer treatments. Figure 2 shows actual height growth from 1990 to 1993. Table 1 compares the various wood chip mulch treatments to the control block growth over the past three year period.

Three of the six poplar trees in the control indicated complete mortality with no evidence of new sucker growth. No other treatment block suffered mortality, but die-back was encountered in the blocks that were nitrogen loaded in 1990 and 1991 (i.e. blocks 3 and 5). The application rate of the nitrogen (urea), was excessive (600 kg/ha of elemental nitrogen), so die-back is most likely a direct result of this.

In general, the plantation demonstrated that the urban waste wood improved the physical growing condition for trees. Although, the plantation was small and not of the random block type, it effectively demonstrated that trees achieve better growth rates, and are less susceptible to mortality with the application of the waste wood chips, compared with no mulch application at all.

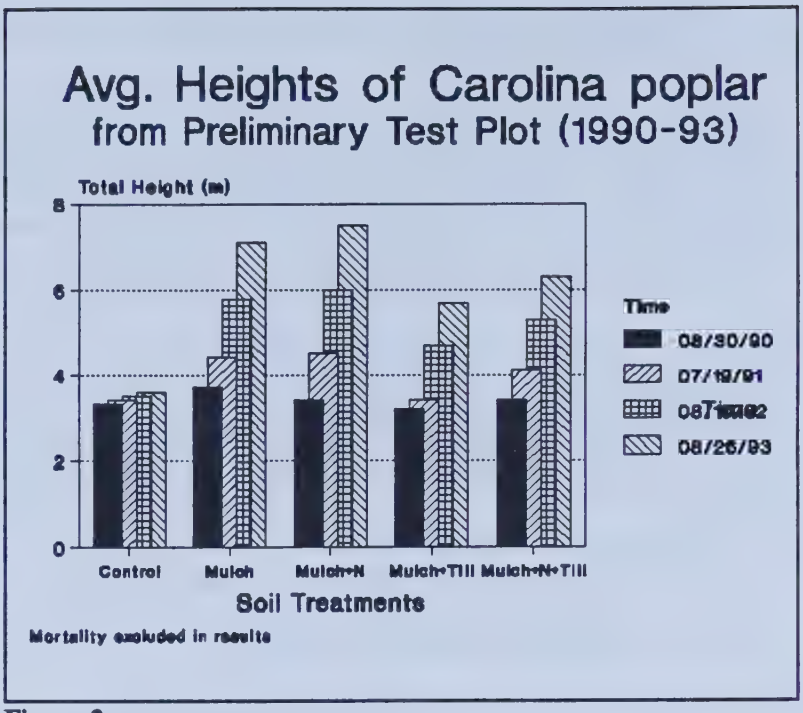


Figure 2

Table 1 Carolina polar Height Growth achieved after 3 years (Control vs. 4 Treatments)

TREATMENT	08/30/90 Ht.	Growth @ (1993)	Height Diff.	+/- (95% C.I.)	
Grass/Control	3.3 m	0.3 m	-		-
Mulch	3.7 m	3.4 m	2.9		0.36
Mulch + N	3.4 m	4.1 m	3.8		0.20
Till Mulch	3.2 m	2.5 m	2.2		0.87
Till Mulch + N	3.4 m	2.9 m	2.6		0.15

All individuals encountering die-back and mortality excluded from analysis

Soil/Wood Chip Interactions (1991)

After a year and a half, with the wood chips occupying the landfill site at an average thickness of 20 cm, soil samples were taken and analyzed. Seven grass covered and six 20 cm mulch covered soil samples were tested. Statistical differences (at the 95% confidence level) were found for both manganese and iron. Both elements were found to be elevated.

Table 2 Manganese and Iron levels found on Mulch and Grass Covered Soil

TREATMENT	ELEMENT	ELEMENT LEVEL (ppm)	+/- (95% C.I.)
Grass Cover	Manganese	15.80	8.42
20cm Mulch	Manganese	87.20	29.27
Grass Cover	Iron	49.14	8.44
20cm Mulch	Iron	76.17	7.84

What is the source of these elements if the wood chips themselves possess very low levels of the elements? The factor responsible for these elevated level is due to the rather thick application of wood chips (up to 1 metre in some areas) at the site during this initial period. Wood chips do allow for aeration, but if the thickness is excessive, an oxygen poor environment will develop. In aerated soil, iron and manganese are found in the form of Fe^{3+} and Mn^{4+} (Glinski *et al.*, 1985). Further, Glinski *et al.*, (1985) states that with a lessening of the O_2 concentrations, Fe^{2+} and Mn^{2+} are increased in concentration, and tend to precipitate to the surface. This can be avoided keeping the pure wood chip cover less than 20 cm. If the chips are incorporated into the clay, tree roots can then utilize this medium which is found closer to the surface (see also Planting Operation (1993) and Discussion sections), and thus take advantage of a much improved soil oxygen content.

Austree Plantation (1992)

In June of 1992, a one hectare plot was ploughed and subsequently planted with 1000 Austrees (*Salix alba x matsuda*). The site was then covered with 15 cm of wood chips. On June 21, 1993, a top dressing of various fertilizer treatments were applied. After one month, the following results were produced.

Table 3 Austree Plantation Fertilizer Trial after 1 Month Growth

TREATMENT	No. Samples	Mean Growth	S.D.of Growth	+/- (95% C.I.)
Mulch Only	27	42.85	20.64	8.18
Mulch + 1N	26	63.58	28.29	11.43
Mulch + 2N	29	54.86	16.72	6.37
Mulch + 2N+PK	30	58.83	20.63	7.68

Note: 1N = 100kg of elemental nitrogen per hectare

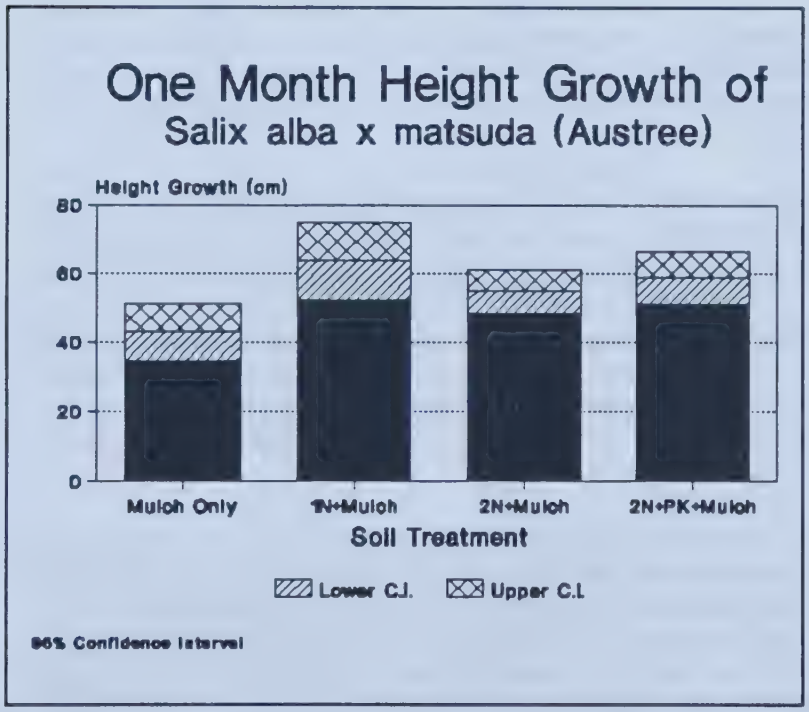


Figure 3

Even after only one month, statistical differences are becoming evident. With wood chips, nitrogen becomes tied up. Examining Table 1 and Table 3, the results indicates that mulch improves the growing medium for tree growth on its own, but with the further addition of nitrogen, at an appropriate level, tree growth is improved by almost 50%.

Planting Operation (1993)

In late April of 1993, a total of 15500 seedlings were planted, 9000 of which were planted in plantations. Site preparation for the landfill included the following: chip grading to a 15 cm thickness; ploughing the chips into the clay soil in October of 1993; and a second ploughing operation in mid-April of 1993. Of the tree species available from, and donated by, the MNR Midhurst Nursery, Carolina poplar (*Populus canadensis 'Eugenei'*), black locust (*Robina pseudoacacia*), and Norway spruce (*Picea abies*), fared the best. Red pine (*Pinus rubra*) and white spruce (*Picea glauca*) are currently suffering, and white cedar (*Thuja occidentalis*) are declining in the exposed areas.

Little analysis, so far, has been done on these newly planted seedlings. Some general comments can be made though. On one black locust plantation half the trees were planted on the mulch preparation medium, while the other half were planted in the grassed medium. After two months since being planted, leaf flushing was shown to be about 95% on the mulch medium compared to a 30% activity rate within the grassed area.

Two healthy Norway spruce individuals were removed, representing both three months growth in grass and three months growth in the ploughed clay/wood chip medium. Nutrient analysis of the plant tissue is currently being processed. Physical inspection of the two individuals indicated the following about the mulch effects on seedling development:

- Needle Production - more extensive
- Needle Length - shorter
- Needle Colour - lighter green
- Root Expansion - more extensive

The results indicate classic nitrogen deficiency symptoms, but they also indicate good drainage, aeration, moisture level, weed suppression, and other positive physical characteristics. Therefore, future site preparation, should include the dispersement of nitrogen.

Discussion

Clay caps of landfill sites are rather poor environments for tree establishment to begin with. The cap is usually a hard clay, designed to restrict water penetration into the underlying garbage. Any root systems of planted trees on such clay caps will have severely impeded root development. This is because the medium is very compact in nature and lacks good soil aeration and drainage.

Landfill sites exude a multitude of gases from below, with the largest fraction being methane and carbon dioxide. Physically, methane would displace most of the atmospheric oxygen found in the root zone. Since methane is a non-polar molecule, chemical effects on plant growth are negligible due to it being relatively nonreactive.

The first major step in the rehabilitation process is to promote oxygen penetration into the root zone of the clay. Further, weed competition should be checked with mulch, but at a thickness where it does not hamper oxygen infiltration. Therefore, it would be advantageous to have wood chips spread on top of the clay cap and subsequently ploughed into the clay. This would create paths for oxygen absorbtion, and as well, help inhibit the establishment of weeds.

Obviously, decomposing wood will demand an amount of nitrogen. Bergman *et al.* (1974) found that most deterioration of wood chips occur in the first three months of storage. It is therefore suggested that the wood chips be allowed to decompose for one or two years before any planting operation is initiated. The chips could be stored at the site in question, or at an aging yard. Another option is to compost the chips through the addition of a nitrogen source (eg. chicken manure, fertilizers). However, if weed control is the key issue, then it would be better to forego the addition of any nitrogen until just before the tree planting operation.

Observations so far indicate that leachate production has not increased since the wood chips placement. It was speculated that the chips, with their affinity for moisture, would promote water infiltration into the cap (since any

captured water would be released at a slower rate compared to the sole compacted clay cover which would direct any precipitation rapidly off the locale).

Further study regarding mulches effects on leachate production will persist. It is felt that increased water and oxygen infiltration will help rehabilitate the site. Radnoff (1992) asserts that by restricting the infiltration of water into the landfill, biodegradation of organic materials in the refuse will be inhibited due to lack of moisture. Further soluble compounds that leach out of the wastes will do so at a much slower rate but at a higher concentration. Radnoff (1992) maintains that for long-term leachate management, it is better to increase water infiltration to enhance biodegradation of the organic component of the wastes while flushing out soluble contaminants. Contaminants will be leached out of the refuse at an earlier stage in the lifespan of the landfill and can be dealt with by treatment or other measures. This will ensure that the majority of the leachate is produced while the engineering systems are still functioning (Radnoff, 1992).

Reports have been written by Morley (1984), Ehrenfeld (1987) and Cureton et.al. (1991) that show that trees can be used to remove excess nitrogen from household effluent, industrial effluent, and landfill leachate. Morley (1984) found that effluent increased poplar tree growth by 120% in comparison to the control. Leachate recirculation trials will be addressed when plantation trees have reached free to grow status.

Conclusions

The major concerns of a closed landfill site are the production and release of leachate and greenhouse gases. Other concerns include the erosion of the cap, long terms of costly surveillance and continued maintenance, and also the inability to amend the idle locale.

The conclusions that can be drawn from the presented results and others not mentioned here are the following:

Waste Wood Chips:
◦ improve survivability and growth of seedlings ◦ retain soil moisture, allows for better root growth ◦ reduces rodent damage, (exposed to potential predators) ◦ reduces weed competition ◦ adds organic matter, decomposes in a few years ◦ creates better soil structure (drainage, aeration) ◦ protects against soil erosion ◦ removes the need for herbicides ◦ diverts waste wood from landfill solid waste stream ◦ improves soil microbial population ◦ acts as a temperature buffer ◦ produce tannin, a by-product of wood decomposition, which has an affinity for heavy metals in landfill leachate ◦ Tie-up of some soil nitrogen

It is suggested that creating a pasture or golf course can only be, at best, a band-aid solution. Real steps must be taken to redirect present waste streams and accelerate existing landfills amelioration, or we shall remain stewards of not only our garbage but our parents garbage for all time. Improving the soil structure, and tree growth medium, in general, is a step in the right direction.

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Sponsors of the Project:

- W.C.I. Wood Conversion Inc.
- Regional Municipality of Peel
- NRC
- Tree Plan Canada
- Ministry of Natural Resources, Midhurst Nursery

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SESSION III: WETLAND RESTORATION

DRAINAGE DESIGN AND WATER QUALITY MONITORING FOR WOODED SWAMPLAND RESTORATION

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ABSTRACT

As found in many rural areas of southern Ontario, wetlands, especially swamps, have bee drained and used for agriculture. The restoration project site described in this paper was tile-drained and cleared for a period of seven years. Natural drainage characteristics of the site were severely disturbed during this period.

The approach taken to restoring swampland characteristics relied primarily on restoring the natural ebb and flow of drainage through the site. This necessitated an understanding of seasonal precipitation as well as the hydroperiod characteristics of other local swamps. Drainage from the site was monitored along with a wide variety of water quality parameters over a period of 12 months during 1992-93. This paper describes the drainage characteristics of this pilot project as well as general water quality and the value of follow-up monitoring with similar projects.

This project undertook to restore swampland vegetative cover to approximately 3 hectares of marginal farmland that had previously been tile drained and under active agriculture for seven years.

Drainage

A low berm was installed across the lowest end of the site to effectively block surface drainage. Pre-existing 30 centimeter collector tiles were connected to standard Hickenbottom riser and standpipe hardware to provide a drainage outlet for the site. Since much of the flow into the site was groundwater from surrounding morainal deposits the head control was maintained with the above ground standpipe. This damming approach was necessary to aid in restoring hydroperiod characteristics to the site that mimic that of other local forested swamp ecotypes.

By allowing standing water to pond and slowly drain out of the site it was intended to provide conditions condusive to the development of vegetative communities as found in local swamps. It was expected that ponded water would suppress vegetative communities previously established following tile drain installation and would encourage the re-establishment of remnant vegetation as found in adjacent swamp lands. The head level of ponded water was monitored weekly for one year by means of a staff gauge at the standpipe outlet. More frequent readings were taken during selected storm events.

Hydroperiod

Fluctuations in the pond head level indicated that the site hydroperiod was buffered by continual ground water input and the absorbant capacity of a pre-existing organic mat and organic soils overlying the clay base of the site. This buffering characteristic resulted in very gradual decay of drainage and associated pond head lowering following storm events. During drier months of the year the absorptive capacity of the site frequently precluded any change in pond head following storm events. During spring and autumn, when the organic mat was saturated, moderate storm events resulted in pond head peaks within 3 to 5 hours and the resultant decay was extended for up to 36

hours afterwards.

Water Quality

A water quality monitoring program was established in the spring of 1992 to assess the effect of the project site discharge on the receiving waters of Salem Creek, a cold water stream with resident brook trout population. Samples were taken bi-weekly between March 1992 and May 1993 from ponded water in the project site, below the outlet drain and above the outlet drain in Salem Creek. These were analyzed for a total of 19 parameters through the assistance of the Ontario Ministry of Environment regional laboratories in London, Ontario.

Analytical parameters were:

Biochemical Oxygen Demand, Free Ammonia, Total Kjeldahl Nitrogen, Nitrite, Nitrate, Total Phosphorus, Dissolved Reactive Phosphorus, Dissolved Organic Carbon, Suspended Solids, Calcium, Magnesium, Hardness, Alkalinity, Chloride, pH, Conductivity, Colour, Turbidity, and Temperature.

Data was graphed and analyzed for trends prior to statistical analyses. A variance ratio test which compares data sets on the basis of internal variability and a two sample t-test which compares data set means were used to derive statistical comparisons at a 95% confidence level. The main concern was that sample stations above and below the discharge outlet show no significant difference in parameter values.

Statistical analysis indicated no significant effect of the project discharge on the receiving waters of Salem Creek. The greatest variability was found in comparing variance of macronutrients, B.O.D., and D.O.C. between the project site and both sites on Salem Creek. Clearly the project site had parameter concentration peaks which could be tied to typical wetland fluxes associated with the overwinter senescence and break down of plant material. Discharge from the project site on an annual basis was so low that the receiving waters were not adversely affected; higher runoff in the spring was diluted by correspondingly higher levels of flow in the receiving waters.

The success of this project may be used to developed a longer term program of swampland conversion of marginal wet farmland throughout the Maitland River watershed.

LANDSCAPE ECOLOGY, AVIAN INFORMATION AND THE REHABILITATION OF WILDLAND COMPLEXES IN THE GREATER TORONTO AREA

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ABSTRACT

It is proposed that land regeneration projects should consider the total landscape or landscape ecology of a site. This holistic approach would extend management plans that link the replacement of the vegetation component with returning habitats necessary for the faunal component. Furthermore, the pattern of land use or landscape fragmentation is important for the successful rehabilitation and ongoing management of the landscape. These concepts and their implications for planning will be addressed in this paper with specific reference to the rehabilitation of a wildland/wetland complex on the Black River, Georgina Township, located in the Greater Toronto Area (GTA). This unique landscape includes remnant old-growth forest and vulnerable avian species but is under increasing pressure of fragmentation from exurban development. The results of a habitat fragmentation study comparing bird populations and diversity between this site and several more human-modified complexes in the GTA will be presented.

Introduction

Within the Greater Toronto Area many of the most significant and extensive greenland features are located in the exurban landscape. Unfortunately, little is known of these countryside greenlands in the South Lake Simcoe Watershed and on the Oak Ridge Moraine since they have primarily been located in countryside landscapes, away from large populations and in the past there has been little need to concentrate on them. In the last decade however, the proliferation of residential estate development in these natural areas combined with aggregate extraction operations, landfill dumps, and large scale utility projects to service the metropolitan centres of Metro Toronto have had a devastating impact on the diversity and integrity of these countryside wildlands. If sound land use decisions and conservation, maintenance and rehabilitation of natural areas is to occur in the GTA in the future, improved methodologies and strategies for acquiring and integrating information on the floral and faunal species, in a rigorous and planned way, will have to be developed.

Even within the GTA where, compared to the rest of the province, past inventory and research work is quite extensive and documented, a reliable base of environmental information does not exist. Yet, a data base of this nature is vital for the development of strategies concerning landscape rehabilitation. This paper presents the preliminary results of an ongoing project, funded by the Ontario Ministry of Natural Resources, that addresses the lack of an information base and the effects of human disturbance on bird species uniqueness, diversity and type (eg. forest interior species) for several wildland complexes in the GTA. It is proposed that the level of human activity or disturbance and the pattern of land use will affect the survival success of species populations and will be reflected in the levels of unique and rare species, diversity and specifically indicator species groups of raptors, cavity nesters and neo-tropical migrants.

Fragmentation of Landscapes

Southern Ontario and especially the Greater Toronto Area (GTA), has seen the rapid decline of many land cover types such as old growth forests and wetlands that are important habitat-specific types for many floral and faunal species. Their loss to rural agriculture and open space urban sprawl has had a major impact on species diversity and populations through the loss of a continuous cover of forest, wetland and wildland areas. This has led to the dissection or fragmentation of the land creating a mosaic of land cover referred to as the landscape.

Fragmentation results in the decline of gene pools, the loss of species that only occur in large patches of uninterrupted habitat, the endangerment of low-density, wide-ranging species, and the invasion of alien species. As fragmentation increases, many more suitable habitats for human-adapted species dominate the landscape and it becomes increasingly less hospitable to natural wildlife communities (Harris and Gallagher, 1989; Wiens, 1989).

The survival of species in the landscape is affected by the pattern of the landscape and landscape heterogeneity. It is often the structure of an entire landscape mosaic rather than the size or shape of individual patches that is important. Under certain circumstances smaller patches or a combination of small patches may contain more species than large patches (Simberloff and Abele, 1982; Loman and Von Shantz, 1991). However, certain types of species, usually the rare or unique, are susceptible to extinction in increased habitat patchiness and fragmentation (Butcher et al., 1981; Conner and Rudolph, 1991).

The problem of loss of habitat in the global community, especially Amazonia, and the impact on neo-tropical migrants has been reported in recent years (Wiens, 1989; Askins et al., 1990). The reverse situation, loss of habitat for the breeding and migration of these birds in North America is only now being recognized as significant (Askins et al., 1990). However, it has been difficult to establish long-term evidence of this phenomenon since little information is available on the population trends and landscape space requirements of many species.

Baseline Information and Historical Landscapes

Landscapes and habitats are dynamic and ever-changing over time. Often, little is known about the previous composition of botanical and faunal assemblages in places, especially the pre-European settlement characteristics of specific locales. For many years, assumptions have been made that may be erroneous as in the case of the revision of the extent of the historical savannas in southern Ontario (Catling et al., 1992). In the GTA, this is especially difficult since much of the presettlement forest has been cleared. It is possible to reconstruct the forest canopy from surveyor's records (Gentilcore and Donkin, 1973) but this only provides an overview of the dominant tree species, especially those that were a desired timber resource. It does not provide insight into the changes or dynamics of the forest ecosystem, especially the plant/animal relationships within these forests.

To develop a rehabilitation strategy that considers the landscape, it is necessary to establish a starting point, specifically, baseline values for a site. The composition, structure and functions of the land components (eg. fields, forests, and population centres) for an area have to be determined at the scale of the landscape with the focus on the interactions between the different types of land components or units (Moss, 1983). This is a holistic or ecosystem approach and the basis of research in the field of landscape ecology (see Forman and Godron (1986) for a general review of landscape ecology). This approach recognizes the impact that the land use within a land unit has on the surrounding, geographically connected units. For example, in a riparian system, the river, floodplain, slope and upland forests all combine to control the transport of nutrients and movement of species in river corridors (Forman and Godron, 1986). Therefore, rehabilitation should not simply be the reforestation of an area but it should have as a goal the recovery of the landscape system with the aim of achieving a "healthy" landscape. Soule and Kohm (1989) noted guidelines need to be developed that will help diagnose when the critical processes of a managed landscape are beginning to malfunction. Research aimed at both understanding degraded ecosystems and enhancing their productivity and diversity is a priority.

Bird Species as Indicators of Ecosystem Stress

The state of the landscape can be assessed by measuring the quality and quantity of fauna present at a site. Species rarity or uniqueness and measures of diversity have been typically considered as defining the significance and therefore, value of an area usually within various levels of significance (eg. regionally, provincially and nationally rare). In practice, the presence of more species and uncommon species makes an area more valuable, a habitat of higher quality retains a greater number of species. Less common species are frequently found in remaining higher quality habitats with their uncommon status resulting from habitat loss or degradation. The loss of habitats that retain a larger diversity and unique species constitutes a greater impact (Cable et al., 1989). However, diversity by itself does not necessarily provide information on specific environmental stress. A high diversity may simply indicate a large number of species that are urban-oriented or edge species which are adapted to fragmented landscapes (Loman and Von Shantz, 1991). It is necessary to examine the details of the types of species that constitute the diversity. These can be considered as groups of indicator species or response guilds (Croonquist and Brooks, 1991) that are representative of a particular use, ecosystem, or management concern and changes in the population of these species will reflect the effects of management decisions (Soule and Kohm, 1989).

In this study, avian species have been used to measure the effects of fragmentation and disturbance. Cable et al. (1989) recommends the use of birds in habitat assessment because relative to other taxa, they are conspicuous, easy to identify, and they occur in nearly every habitat type, thereby minimizing field time. Several avian groups of indicators have been selected including raptors, cavity nesters and neo-tropical migrants. Raptors occupy the end positions of the food chain and thus are good indicators of disturbance. Also some species have habitat-specific nesting and foraging requirements such as the Red-shouldered hawk (*Buteo lineatus*) that are quite dependent on the landscape pattern (Bosakowski et al., 1992). The presence of cavity nesters provides an indication of the availability of dead wood or snags that are available for nest sites, foraging and perching platforms (Schreiber and deCalesta, 1992). As a forest matures and reaches the stage of "old growth" the presence of cavities in older trees and snags increases and therefore, this stage in forest growth should be considered as an important component in the management of forest ecosystems. Neo-tropical migrants are threatened both by the loss of their winter habitat in the tropics as well as the decline of suitable breeding sites in Ontario. Many of these species are dependent on large tracts of interior forest for successful breeding and are considered as area-sensitive. The fragmentation of forest cover into smaller woodlots is a possible cause of their declining breeding success.

Site Description and Research Methodology

The sites investigated include the Black River, Uxbridge Brook and Milne Park wildland/wetland complexes. The first two sites are in the Lake Simcoe basin on the north slope of the Oak Ridges moraine and the latter is found in the upper Rouge River system on the south slope of the moraine (Figure 1 shows the relative position of each site within the GTA). Each has a ponding or small lake either from man-made or natural riverine origin causing a significant impoundment of long-term presence.

These riverine/lake systems are experiencing varying levels of pressure from human activity, forming a continuum of disturbance allowing for the comparative analysis and establishment of baseline values. Although it is difficult to establish a natural baseline measurement to compare sites to the previously unaltered landscape, especially in this area of Southern Ontario, the Black River site is a good example of a relatively undisturbed forested riparian landscape, one of the few remaining in the GTA. This area is a dynamic natural wetland/wildland complex at the confluence of two small riverine systems. The area is particularly unusual in the GTA in that it is relatively unaccessible and has virtually no development on the shores of the river and much of the area around. However, some modest development pressures are increasing resulting in the fragmentation of the landscape from agriculture and urban influences. This site has relatively large sections of forest interior dissected in several locations by agricultural fields. The general pattern of this fragmentation is presented in Figure 2.

The Uxbridge Brook site, similar to the Black River in size and location, is a riparian system draining from the Oak Ridge Moraine northward to Lake Simcoe. The river has moderate wetland development at both ends of a natural lake basin. It is a rural site that is experiencing increasing disturbance from residential/cottage development around the lake and the establishment of a subdivision on the southeast uplands. The majority of the forest cover has been selectively removed for cottage lots and while there is still a complete tree canopy in places, the forest system has been for the most part replaced.

Finally, Milne Park, part of the Rouge River system, is found close to Toronto, within the urban community of the Town of Markham, and is situated in an area of extensive development. The pond is man-made and suffers greater disturbance than the other sites from the surrounding population centres and the use of the area for recreation. There are small pockets of forest remaining in the park but these only fringe the river and do not provide a continuous cover. There has been extensive removal of tree species and replacement with lawn and individual plantings typical of an urban park setting.

The status of the breeding birds for each site was determined over two seasons, 1992 and 1993, commencing in late May until mid-August. The species type, population size and breeding success was measured as well as species behaviour and their spatial utilization of the landscape, the movement of species within and between landscape units for various functions such as breeding and foraging. The initial results of species diversity, uniqueness and indicator groups will be presented in this report while behaviour and spatial patterns will be addressed in a later paper.

The sites were sampled primarily in the early morning when the majority of species were most active, from 6:00 until 11:00 am. However, every fourth sample period was scheduled in the evening, from 2:00 until 9:00 pm., to include those species more common at this time, such as Common nighthawk (*Chordeiles minor*). Approximately equal field hours, by foot and canoe, were conducted at all sites, with 100 hours of field time by a team of two at each site during each season.

The limited area of the study sites and size of the research team made it possible to cover all of one site during a research period and because of the fragmented nature of the sites, it was decided to sample the entire site rather than to limit the research to sample plots. This ensured that all unique and indicator species would be identified and that fragmented landscape components, that were smaller than a standard research plot, would not be ignored.

Results

Uniqueness and Rare Species

As mentioned, there are several levels at which the rarity of species are recognized. In Table 1, species rarity was considered at the national (Committee on the Status of Endangered Wildlife in Canada or COSEWIC), provincial (Ontario Rare Breeding Bird Project or ORBBP) and regional level (eg. Lake Simcoe Regional Conservation Authority (LSCRA) and Metro Toronto Regional Conservation Authority (MTRCA)). The greatest number of rare species was found at Black River and the lowest at Milne Park, showing a decline from the least to most disturbed site. At Black River, there was breeding evidence of Red-shouldered hawk, Least bittern (*Ixobrychus exilis*), and sightings of Eastern bluebird (*Sialis sialis*) and Cooper's hawk (*Accipiter cooperii*) all listed as vulnerable by COSEWIC (Cadman et al., 1987). There are also sightings and historical records (Harpley and Pollock, 1991) of Sedge wren (*Cistothorus platensis*), Hooded merganser (*Lophodytes cuclullatus*), and Caspian tern (*Sterna caspia*) recognized as rare by the LSCRA.

At Uxbridge Brook, there were only several unique species observed. These included breeding evidence of Red-shouldered hawk and sightings of Caspian tern and Black-crowned night heron (*Nycticorax nycticorax*), the latter is recognized as rare by the LSCRA. The only sighting of a nationally rare species at Milne Park was Caspian tern, although there were sightings of Great egret (*Casmerodius albus*) and Black tern (*Chlidonias niger*), both recognized

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as rare by the MTRCA.

Diversity

The preliminary results indicate that the diversity of breeding birds is inversely related to the level of human disturbance, habitat loss and fragmentation. A comparison of species diversity, compiled over the two seasons, for the three sites is presented in Table 1. Black River, with more forest cover and less human activity, had the greatest avian diversity with 92 species recorded. Uxbridge Brook had a lower number identified (73 species) and the lowest diversity was found at Milne Park with 57 species identified. Especially noteworthy at this site are the lack of species sensitive to environmental stress.

TABLE 1
LOCATION AND NUMBERS OF RARE BIRDS AND SPECIES DIVERSITY

Common Name	Scientific Name	Location		
		Black River	Uxbridge Brook	Milne Park
Hooded Merganser [a]	*Lophodytes culcullatus*	1	-	-
Caspian Tern [abc]	*Sterna caspia*	2	2	3
Black Tern [bc]	*Chlidonias niger*	-	-	4
Great Egret [b]	*Casmerodius albus*	-	-	1
Least Bittern [abc]	*Ixobrychus exilis*	1	-	-
Red-shouldered Hawk [abc]	*Buteo lineatus*	1	1	-
Sedge Wren [c]	*Cistothorus platensis*	2	-	-
Total Diversity		92	73	57

a Committee on the Status of Endangered Wildlife in Canada
b Ontario Rare Breeding Bird Project
c Lake Simcoe Regional Conservation Authority/Metro Toronto Regional Conservation Authority

Indicator Groups

Raptors

There were a greater number of species of raptors found at the Black River site (a total of six species) than the other two sites although there were similar numbers at Uxbridge (five) (see Table 2). At Milne Park only Sharp-shinned hawk (*Accipiter striatus*) and Osprey (*Pandion haliaetus*)were observed. The other sites had records of Broad-winged hawk (*Buteo platypterus*), Red-tailed hawk (*Buteo jamaicensis*), Red-shouldered hawk, Osprey and Sharp-

shinned hawk and there were also sightings of Northern harrier (*Circus cyaneus*) at Black River.

The presence of Red-shouldered hawk supports the findings of Bosakowski et al. (1992) who observed that the species nests in areas of larger wetlands and closer to streams in forest areas with a greater proportion of coniferous and mixed forest which is typical of the Black River and Uxbridge Brook sites. Their findings also suggest that the species is area-sensitive.

TABLE 2
LOCATION AND POPULATION OF RAPTORS

Common Name	Scientific Name	Location		
		Black River	Uxbridge Brook	Milne Park
Sharp-shinned Hawk	*Accipiter striatus*	3	2	2
Northern Harrier	*Circus cyaneus*	2	-	-
Broad-winged Hawk	*Butei platypterus*	1	2	-
Red-tailed Hawk	*Buteo jamaicensis*	2	2	-
Osprey	*Pandion Haliaetus*	3	2	2
Turkey Vulture	*Cathartes aura*	2	-	-
American Kestrel	*Falco sparverius*	1	1	-

Cavity Nesters

Table 3 indicates that similar species of cavity nesters were observed at all sites, indicating a high presence and availability of cavities and snags. There are higher populations of most species at Black River, especially those more sensitive to disturbance, Wood duck (*Aix sponsa*), and fragmentation, Great crested flycatcher (*Myiarchus crintus*). Urban-related species such as the Downy woodpecker had similar populations throughout.

TABLE 3
LOCATION AND POPULATION OF CAVITY NESTERS

Common Name	Scientific Name	Location		
		Black River	Uxbridge Brook	Milne Park
Wood Duck	*Aix sponsa*	10	2	3
Yellow-shafted Flicker	*Colaptes auratus*	10	7	4
Downy Woodpecker	*Picoides pubescens*	3	4	2

TABLE 3

LOCATION AND POPULATION OF CAVITY NESTERS

Common Name	Scientific Name	Location		
		Black River	Uxbridge Brook	Milne Park
Hairy Woodpecker	*Picoides villosus*	1	0	2
Great Crested Flycatcher	*Myiarchus crinitus*	12	7	5
Tree Swallow	*Iridoprocne bicolor*	31	21	5

Neo-Tropical Migrants

Although there were many species found at the sites that could be included in this category, a small group of species have been compiled in Table 4 as a representative sample to highlight trends between sites. From the table, it is obvious that the number of species and their populations were lowest at Milne Park and greatest at Black River. Species such as Veery (*Catharus fuscescens*), Wood thrush (*Hylocichla mustelina*) and Scarlet tanager (*Piranga olivacea*) were not recorded during the two years at Milne Park. Other species, not listed in Table 4, that were also not found at Milne Park but did occur at the less-disturbed sites included Chestnut-sided warbler (*Dendroica pensylvanica*), Golden-winged warbler (*Vermivora chrysoptera*) and Alder flycatcher (*Empidonax alnorum*). Ovenbird (*Seiurus aurocapillus*), Wood thrush and Veery, had the greatest populations at Black River. These species are forest floor nesters, preferring sites of undisturbed forest interior which are more common at the Black River site.

TABLE 4

LOCATION AND POPULATION OF NEO-TROPICAL MIGRANTS

Common Name	Scientific Name	Location		
		Black River	Uxbridge Brook	Milne Park
Eastern Pewee	*Contopus virens*	6	6	2
Scarlet Tanager	*Piranga olivacea*	2	0	0
Veery	*Catharus fuscenscens*	9	2	0
Wood Thrush	*Hylocichla mustelina*	6	4	0
Red-eyed Vireo	*Vireo olivaceus*	9	4	0
Ovenbird	*Seiurus aurocapillus*	22	12	5

Discussion

For each of the avian measures there was an increase in values from the most fragmented and disturbed site, Milne Park, to the least, Black River. The number of rarities was higher at Black River, the diversity was almost double and for each indicator group, raptors, cavity nesters and neo-tropical migrants, the numbers and populations of species were greater. These results combine to highlight the impact that human activity and fragmentation has had on these sites. Milne Park, experiencing the pressures of urban development and recreation, has the lowest values, especially those of the indicator groups, emphasizing the environmental stress on the faunal component of the landscape at this site.

Uxbridge Brook, which could be considered as a transition site, with respect to disturbance, had values that were continually between the other two sites. Specifically, the numbers for raptors and cavity nesters were similar to those at Black River but the neo-tropical migrants were lower. This indicates that the main stress on this site is the loss of forest interior. The preservation of the older trees in the cottage residential area provides cavity sites while the surrounding agricultural fields and riverine forests provide sites for raptors but the removal of the forest and its increased fragmentation has reduced those species dependent on this habitat.

The results emphasize the importance of the Black River site and its usefulness as a baseline for avian breeding information. The second phase of this project will be to relate species behaviour of the indicator groups and rare species with their spatial use of the landscape. This information will be used to develop a rehabilitation strategy for the Black River complex to maintain and enhance the health of this landscape system.

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VEGETATIVE REGENERATION WITH SWAMPLAND HYDROPERIOD CONTROL

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ABSTRACT

In many cases, where swamps and other wetlands have been drained for agricultural purposes, a potential source of propagules remains viable and available for restoration purposes. This source of plant material appears to be suppressed by drainage and subsequent drying of the upper soil layers especially the organic mat in this project site. The approach taken to restoring the vegetative community on this swampland site relied primarilly on restoring the natural ebb and flow of drainage through the site.

Ongoing monitoring has included detailed botanical surveys, hydroperiod characteristics, and water chemistry. This paper described the process of vegetative community change and the gradual regeneration of swamp ecosystem characteristics with hydroperiod control.

FACTORS AFFECTING VEGETATION DYNAMICS ON ACID, METAL-CONTAMINATED SOILS OF THE SUDBURY AREA

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ABSTRACT

The primary factor affecting vegetation dynamics on Sudbury's barren soils is their acidic, aluminum-, copper- and nickel-toxic properties, although certain plant species avoid the problem through genetically-based metal-tolerance. The soil can be detoxified sufficiently to initiate colonization by the surface-application of ground limestone, the dolomitic variety being more effective at certain sites. The drought-vulnerability of seedlings, resulting from toxicity-engendered root growth limitation, is exacerbated by enhanced frost action resulting from the lack of leaf litter. Phosphorus deficiency can be a problem on sandy valley-bottom soils, but most barren soils contain a substantial reservoir of phosphorus and nitrogen in the form of residual organic matter. Both rhizobial and actinorhizal species play an important role in dynamics, and it is likely that the role of mycorrhizae is critical, although more research is required on the latter topic. The seed availability factor is rarely limiting; while the seed bank is small, in most sites the seed rain of light, wind-dispersed seeds is adequate to colonize soil detoxified by liming. The process of "succession" can follow one of three different routes, depending on whether the barrens are left untreated, treated with limestone only, or treated with limestone and a grass-legume seed mixture.

Introduction

Sudbury lies at the southern edge of the Precambrian Shield, in Rowe's (1972) Great Lakes - St. Lawrence Forest Region, which is transitional between the coniferous forest to the north and the deciduous forest to the south. Prior to the advent of the mining and smelting industry in 1883, the area was characterized by extensive stands of red pine (*Pinus resinosa*) and white pine (*Pinus strobus*). One hundred years of logging, fire, soil erosion and enhanced frost action, as well as sulphur dioxide fumigation and copper, nickel and iron particulate fallout from the region's three smelters, have severely damaged the Sudbury landscape (Winterhalder, 1984), giving rise to 10,000 hectares of barren land which form concentric zones around the three smelters. Soils on the slopes have a stony covering that is the result of the combined action of frost-heaving and erosion on the glacial till-derived soil. Extensive rock outcrops also occur, on which shallow pockets of soil can be found, while in the valleys areas of boulder clay alternate with a fine sandy-silty alluvium. On valley sites that once supported a spruce bog or a cedar swamp, barren peatland now remains.

Until recently, the only plants found at "barren" sites were relict individuals of woody species that had survived the stresses responsible for the loss of the original vegetation. Tree species falling into this category were mostly white birch (*Betula papyrifera*), red maple (*Acer rubrum*) and red oak (*Quercus borealis*) in drier sites and trembling aspen (*Populus tremuloides*) in moister areas. While the former three species took on a coppiced form, with suckers arising from the base of a stool, the aspens existed as clonal patches arising from root suckers. Relict shrubs included the common blueberry (*Vaccinium angustifolium*), wild currant (*Viburnum cassinoides*) and red elderberry (*Sambucus pubens*). More recently, metal-tolerant plants, which will be discussed later, have begun to colonize the barrens.

Surrounding the barrens was a 36,000 hectare zone of stunted, semi-barren woodland, characterized by patches of bare soil between the relict, coppiced white birch, red maple and red oak (Amiro and Courtin 1981).

Soil characteristics conformed with the vegetation zones described above, showing a pattern of decreasing pH and increasing copper and nickel content as the three smelters were approached (Winterhalder 1975).

No attempt was made to revegetate the barrens until 1969, because it was believed that the only factor directly limiting the re-establishment and growth of plants was atmospheric quality. However, the announcement by Inco Ltd. in 1969 of its intention to construct a 381 metre smokestack stimulated the Ontario Department of Lands and Forests and Laurentian University to initiate a joint experimental tree-planting programme on a barren site near Coniston and in a stunted, partially-barren red oak woodland near Skead. When the trees on the barren site showed almost total mortality, it was suspected that the direct impact of atmospheric SO_2 was not responsible, and the question of the possible existence of limiting factors other than the direct effect of air pollutants was raised. A number of candidate environmental factors, falling into physical, chemical and biotic categories respectively, were considered, some of which proved to be important, others of which were later abandoned.

Atmospheric Sulphur Dioxide
As A Potentially Limiting Factor To Plant Growth

Dreisinger & McGovern (1964) showed that, under Sudbury field conditions, acute SO_2 injury to vegetation could occur when the following concentrations were equalled or exceeded:

0.95 ppm SO_2 for 1 hour	0.35 ppm SO_2 for 4 hours
0.55 ppm SO_2 for 2 hours	0.25 ppm SO_2 for 8 hours

If any one of these conditions was met in daylight hours from mid-May to mid-October, then the fumigation was termed a Potentially Injurious Fumigation. In a later Ministry of the Environment report, Dreisinger & McGovern (1969) drew pollution zones onto a map of the Sudbury area, based on mean levels of SO_2 from 1953-1967 (Figure 1). The most severely impacted zone formed an ellipse running from southwest to northeast of the Falconbridge smelter, surrounded by a less severe elliptical zone that encompassed the Coniston and Copper Cliff smelters. The zones of vegetation damage of Struik (1973) (Figure 2) are similar, except that in this case each of the three smelters is surrounded by its own ellipse of barren ground.

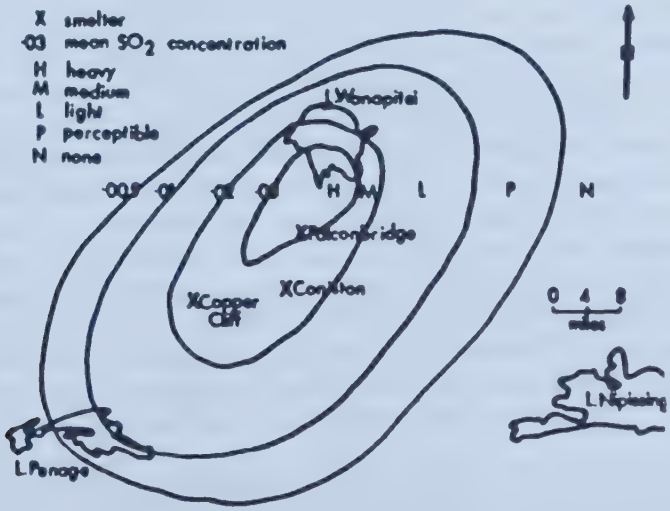

Figure 1: *Pollution zones in the Sudbury area, based on mean levels of SO_2 from 1953-1967 (Dreisinger & McGovern 1969).*

Although the deleterious effect of sulphur dioxide emissions on aquatic environments in the wider Sudbury area have been clearly demonstrated (e.g. Beamish & Harvey 1972), effects on the terrestrial environment are much more difficult to monitor. When an area is already denuded, it is not easy to obtain direct evidence of the direct effect of atmospheric pollution.

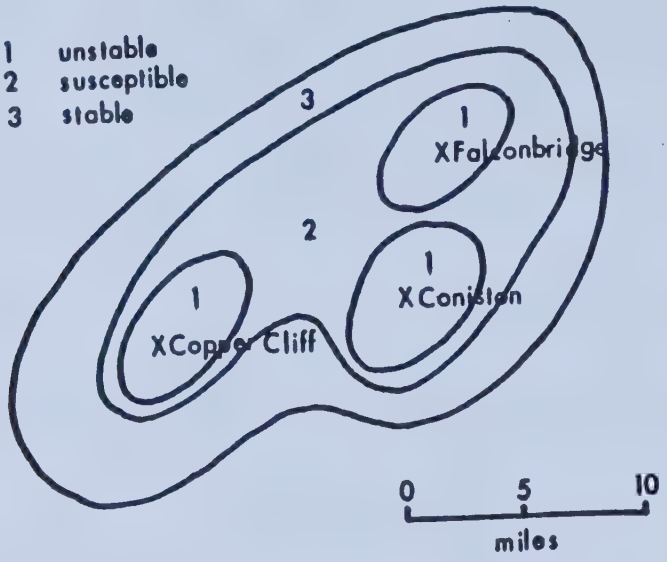

Figure 2: *Zones of "site and vegetational stability", based on aerial photographs taken in 1970 (Struik 1973). "Unstable" sites were barren, "susceptible" sites were semi-barren and "stable" sites were "normal".*

In the 1970s, the Ontario Ministry of the Environment published a series of annual reports on direct SO_2 damage to such species as poplars and birches, and photographic evidence of the sensitivity of white pine to sulphur dioxide was obtained by the Department of Lands and Forests in August, 1968, when sulphur dioxide fumes drifted further southwest than usual, and burned stands of white pines in the Lake Penage area. The Laurentian University/Ontario Lands & Forests "Sudbury Environmental Enhancement Programme" (SEEP) set up experimental transplants of potted white pine in areas of high SO_2 pollution in 1969, but results did not support the hypothesis that high SO_2 fumigation was the factor limitng tree growth. To quote an early progress report (Department of Lands & Forests 1973): "The potted stock trials have demonstrated that the role of recent injurious fumigations of sulphur dioxide has been over-estimated. Most certainly vegetative dieback and soil acidification has resulted from the presence of noxious gases, but at the present time, a much more critical factor responsible for limiting vegetative re-invasion and development is the hostile, impoverished soil medium, in so far as seed germination is possible but initial rooting is curtailed". It was later acknowledged that it is very difficult to measure the "subtle" effects of atmospheric sulphur dioxide on vegetation (J. Negusanti, Personal Communication[1]), and the Ontario Ministry of the Environment turned its attention to measuring the effects of acid precipitation on vegetation by the use of long-term monitoring plots through the Acid Precipitation in Ontario study (APIOS) (Ministry of the Environment 1991).

The ineffectiveness of sulphur dioxide pollution as an agent of permanent denudation is confirmed by studies on old roast bed sites. Early methods of roasting in open beds (Laroche *et al.* 1979) has often been blamed for the creation of the barrens, but as demonstrated by Turcotte (1981), the only roast bed sites that are currently surrounded by

1 Mr. John Negusanti, Phytotoxicology Section, Ministry of the Environment & Energy, 199 Larch Street, Sudbury, Ontario P3E 5P9.

barrens are those in which there is also an old smelter site nearby. It seems that the roast beds produced large amounts of sulphur dioxide, but relatively little particulate metal.

When soil samples were taken in 1969 from each of the Dreisinger & McGovern (1969) pollution zones, chemical analysis showed a mean pH of around 4.0 in the "heavy" zone, around 4.5 in the "medium" zone and around 4.8 in the "light" zone, with soil copper and nickel levels showing a similar trend in relation to fumigation zones (Winterhalder 1975).

Figure 3 (Balsillie *et al.* 1978) shows the striking reduction in Potentially Injurious Fumigations that occurred in 1972 as a result of the closure of the Inco smelter at Coniston and the pyrrhotite sintering plant at Falconbridge, limitation of SO_2 output from the Inco iron ore recovery plant to 250 tons/day, and the introduction of the 381 metre "superstack" at the Inco Copper Cliff smelter, as well as a striking reduction in SO_2 tonnages emitted by both companies. It was expected that the improvement in atmospheric purity would give rise to a rapid improvement in existing vegetation and spontaneous recolonization of the barrens. As discussed below, any recovery has been limited and slow, confirming the hypothesis that soil properties were a more critical factor in the suppression of colonization than air quality. It is clearly true that the occurrence of numerous injurious fumigations during a season will prevent a tree from reaching its full growth potential, and the improved growth observed since 1972 in previously stunted birches and poplars in the moderately-affected zone is partly the result of improved atmospheric quality. In general, however, it is the indirect and historic effect of atmospheric chemistry, by way of the soil medium, that has been the major limiting factor.

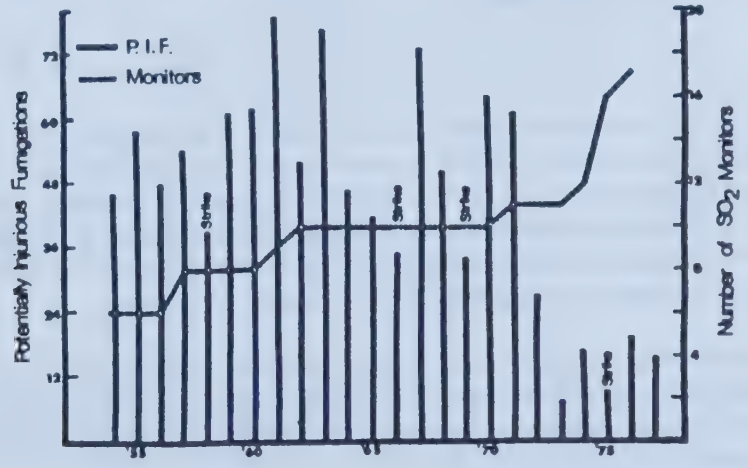

Figure 3: *Number of Potentially Injurious Fumigations occurring in the Sudbury area (Balsillie et al. 1978).*

Soil-based Limiting Factors

Tree-planting trials on the barrens by the Laurentian University-Department of Lands & Forests "Sudbury Environmental Enhancement Programme" (SEEP) in 1969 and 1970 resulted in almost total mortality. Bioassay trials (Hutchinson & Whitby 1974, Whitby and Hutchinson 1974, Winterhalder 1974, Balsillie *et al.* 1978) showed restriction of seed germination and inhibition of root growth to a degree closely related to the distance from the smelters. Roots of seedlings germinated in soil from the barrens show an immediate cessation in growth when the soil is contacted, and the seedling develops a mass of stubby roots on top of the soil. Once the soil dries out, the

seedling dies of drought. In cases where roots are able to penetrate the soil, they do not develop root hairs.

Even in 1993, there are barren areas in the field that support no plant growth, or where growth is limited to metal-tolerant species.

Soil Chemistry

pH and associated effects

The pH of mineral soils collected from hilltops and slopes in a south-southeast transect from the Copper Cliff smelter in the 1970s ranged from 3.3 at 2 km distance to 3.9 at 34 km (Freedman & Hutchinson 1980), and Sudbury soils were not only found to be depressed from the normal pH of 4.5-5.5 to pH 3.2-4.4, but the titratable acidity was found to be very high (2.5-6 meq/100g) and the base saturation from 1-5% (Balsillie *et al.* 1978). Extremes of soil acidity that have been recorded near the Coniston smelter include 2.4 (Hazlett *et al.* 1983) and 2.2 (Hutchinson & Whitby 1974).

The direct effects of low pH on plants are often less deleterious than the indirect effects, and in a highly acidic soil that contains aluminosilicate minerals such as clays, aluminum ions will be present at a phytotoxic concentration. For example, Roshon (1988) found total "available" aluminum levels of around 400 μg/g in several acidic Sudbury-area soils.

Furthermore, the acidity of the soil solubilizes the copper and nickel that has accumulated in the soil from atmospheric fallout, contributing to its phytotoxicity.

Metal contamination

In most "normal" soils, the average total copper content ranges from 15 to 40 μg/g (average = 20 μg/g) (Aubert & Pinta 1977), whereas Hazlett *et al.* (1983) found a copper content of 9700 μg/g in a soil 0.4 km from the Coniston smelter, while even 3 km from the Copper Cliff smelter, Freedman & Hutchinson (1980) described a soil containing 3700 μg/g copper in its organic horizon. Toxicity symptoms often appear at "available" copper levels between 25 and 50 μg/g, the symptoms becoming more severe as the pH drops, whereas Roshon (1988) found Sudbury-area soils with "available" copper ranging from 300 - 900 μg/g in her study.

In most temperate and boreal soils, the total nickel content ranges from 20 - 30 μg/g, whereas Hazlett *et al.* (1983) found a nickel content of 6960 μg/g in a soil 0.2 km from the Coniston smelter, while 3 km from the Copper Cliff smelter, Freedman & Hutchinson (1980) described a soil containing 3000 μg/g nickel in its surface horizon.

Metal-metal, pH-metal and limestone-metal interactions

Experiments on the germination and early growth of *Agrostis gigantea* (redtop), an important revegetation grass in the Sudbury area, suggests that the root growth inhibitory effects of copper and nickel interact in a synergistic fashion, i.e. they enhance each other's phytotoxic effect, giving a total toxicity that is more than the sum of the toxicities of the individual elements. On the other hand, the interaction between nickel and aluminum is antagonistic, the aluminum "protecting" the plant from increased nickel concentrations (Winterhalder 1983).

The effectiveness of limestone application in detoxifying the barren soils appears at first glance to indicate a simple case of a single limiting factor (i.e. low pH). As an environmental factor, however, pH rarely operates alone. Even Dansereau's (1966) "Law of Factorial Control", which distinguishes the limiting or "discrepant" factor from general holocoenotic effects of the environment, does not fully fit the circumstances that exist in the Sudbury barrens soils. We have a case here of an apparent single factor possessing its own particular suite of dependant and interacting subfactors, a sort of "oligocoenosis".

There are a number of mechanisms that could be postulated to explain the detoxification of Sudbury soils by ground dolomitic limestone. In a case where the soil is fully neutralized, it is possible that the toxic metal has been precipitated as a carbonate or a hydroxide. In many cases, however, it is not necessary to raise the pH of a soil to more than around pH 5 to achieve detoxification. The hydroxylation of the trivalent aluminum ion as the pH is increased by liming is almost certainly a factor, but it does not fully explain detoxification, since theoretically the copper ions could still be active inhibitors of root growth. A possible role of both calcium and magnesium ions in the dolomitic limestone employed is in the competitive exclusion of metal ions from the root-hair's exchange complex. The calcium may also play a role in improving membrane integrity.

It may be that magnesium plays yet another role, not as yet understood (Figure 4).

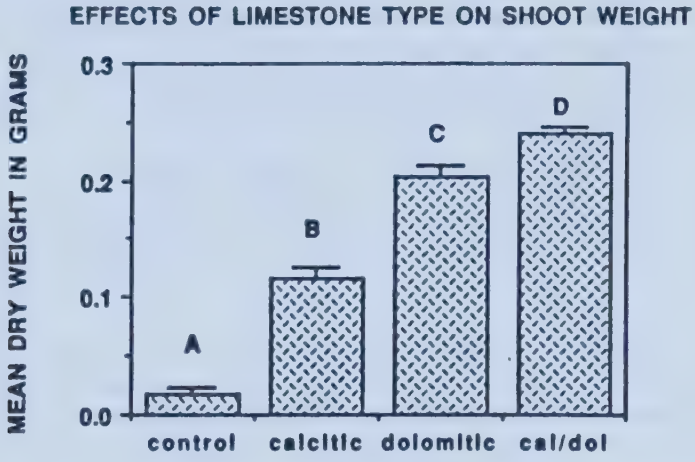

Figure 4: *Effect of limestone type on shoot weight in Mung beans grown on a barren soil from the Falconbridge area.*

Figure 4 shows that mung bean seedlings grown in certain Sudbury barren soils, especially those near the Falconbridge smelter, grow well when limed with dolomitic limestone, but relatively poorly when limed with calcitic limestone. It is hypothesized that this differential effect is the result of induced magnesium deficiency under calcitic limestone treatment and/or of antagonism between magnesium and nickel under dolomitic limestone treatment.

Soil nitrogen and phosphorus

Early field experiments, carried out on the sandy flood plain of Coniston Creek, indicated that soil phosphorus deficiency became a secondary limiting factor to plant growth once the soil was detoxified with limestone (Figure 5). It was later found that plant growth could be initiated and maintained for several years on stony slopes without the addition of phosphorus fertilizer, and it was hypothesized that there was a substantial capital of phosphorus, presumably in the form of phytin (inositol hexaphosphate) and its derivatives, in the "fossil" organic matter derived from the pre-denudation vegetation. Preliminary studies suggest that there is indeed a correlation between soil phosphorus and organic matter content.

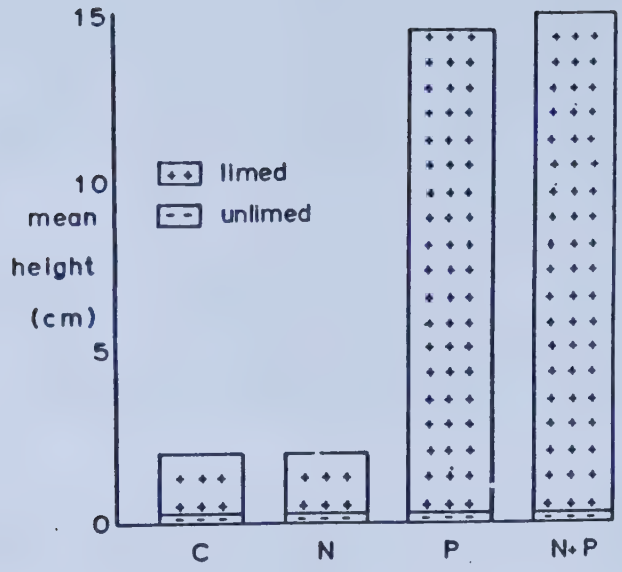

Figure 5: *Effects of lime-phosphorus-nitrogen interaction on the growth of redtop seedlings on sandy Coniston soil, showing that there is no response to phosphorus until the soil is limed, whereas there is no significant response to nitrogen under any treatment.*

Most plants growing on these barren soils seem to possess V-A mycorrhizae (Blundon, 1976), assisting them in obtaining what little soil phosphorus is present. Furthermore, the use of limestone as a soil ameliorant itself assists in the release of phosphorus (Fransen 1991).

Over a period of many years, more phosphorus will undoubtedly be slowly released to the system by the weathering of undecomposed stones in the glacial till, as well as through breakdown of the exfoliating bedrock material. Nevertheless, the total phosphorus "capital" in soil and parent material can limit the type of plant community that will ultimately occupy a site (Beadle & Burges 1949), and in the relatively short term, edaphic factors may prevent the development of the full climatic climax vegetation-type.

Since nitrogen fixation is a biological process, it is dependant on the presence of an ample supply of phosphorus, and preliminary studies (Winterhalder 1987) show a modest correlation between total soil phosphorus content and soil nitrogen measured by the Kjeldahl technique, which is primarily a measure of organic nitrogen.

Native symbiotic nitrogen fixers in the original pine forests of the Sudbury area were probably very rare, and were almost certainly confined to actinorhizal genera such as *Alnus* spp. (green & speckled alder) and *Comptonia peregrina* (sweet fern). Sweet fern can be found as relict plants or stands on barren sites, but it spreads actively once the soil is limed.

Soil calcium and magnesium

Lozano & Morrison (1981), in discussing the mineral nutrition of woody plants in the Sudbury area, suggested that not only calcium but also magnesium deficiency might become a problem once the metal toxicity was eliminated. Although there is so far no direct evidence of either calcium or magnesium deficiency in the soils, the effect of

calcitic limestone on mung beans described above suggests a possible induced magnesium deficiency when the calcium:magnesium balance is altered by calcite application. It is a therefore a fortunate circumstance that the limestone most readily available in Sudbury, from Little LaCloche Island or from Michigan, is dolomitic in nature.

Soil Physical Characteristics

Some of the soils in the Sudbury area present physical problems to plant growth. Probably the most difficult soils are the boulder clays, which take on a gully-eroded, "badland" aspect. These soils do not lend themselves to the surface liming and seeding approach, but are an ideal site on which to plant black locust (*Robinia pseudo-acacia*). The fine silty sands of some of the creek valleys and other lowlands are equally unreceptive to the manual approach, but respond well to the use of light agricultural machinery such as the chain harrow. In fact they lend themselves to a similar treatment to that which is customary for local mill tailings (Peters 1984), which they resemble with respect to particle size distribution. At the other textural extreme are the gravelly soils of the Skead-airport area, which support a sparse oak forest. Here, the free-draining soil and the moisture-consuming trees make the establishment of a grass cover, apart from the native wavy hairgrass (*Deschampsia flexuosa*), difficult.

The loamy soils of the slopes, with their stony mantle, form an excellent seed bed and ameliorant trap, the stones forming a protective mulch. Although frost heaving and needle ice formation are common on these soils, the enhanced root growth that follows liming allows for the stabilization of the heaved areas by plant roots, while the cracks formed by frost action can be beneficial in creating "safe sites" in which seeds and ameliorants can lodge.

Soil Microbiota

Soil microbiota are just as important to vegetation development as are higher plants although, as Parkinson (1978) points out, very few land reclamation projects incorporate soil biological studies into an integrated research programme.

Soil algae are often the first primary producers to colonize mined land, on which they can act as stabilizers and and begin to build up fertility (Booth 1941). Many of the Cyanobacteria, formerly known as blue-green algae and still most conveniently considered with the algae in their role as primary producers, are nitrogen fixers, and they can play an important role in soil nutrient buildup. However, on the acid, metal-contaminated land in the Sudbury area, Maxwell (1991) found that chlorophytes such as the acid-tolerant *Chlamydomonas acidophila*, shown by Twiss (1990) to possess copper-tolerant strains in the Sudbury area, and *Chlorella saccharophila* also recognized (Hutchinson *et al.* 1981) as a metal-tolerant alga, were the main algal inhabitants of the Sudbury barren soils, and that cyanobacteria did not begin to colonize until the soil had been partly neutralized by the surface application of ground dolomitic limestone. She also found evidence that the cyanobacterial inoculum was brought onto the site on the limers' boots. In the Sudbury area, the cryptogamic mat that is often characteristic of barren soils is typically composed of moss protonemata (especially those of *Pohlia nutans*), rather than the more usual filamentous algae.

Other free-living nitrogen-fixers include the bacterium *Azotobacter*. An *Azotobacter*-like bacterium capable of growing on a nitrogen-free agar medium has been isolated from Sudbury barren soils, and nitrogenase activity in this organism has been demonstrated in agar culture by the widely-used acetylene reduction technique. Neverthless, neither the author nor de Catanzaro (1983) has been able to demonstrate nitrogenase activity in the soils themselves, and it is possible that the organisms do not fix nitrogen under soil conditions.

It is likely that, in the case of a tolerant grass such as tufted hairgrass, certain bacteria intimately associated with the roots (the rhizosphere) are nitrogen fixers. In fact, the genus *Azospirillum*, which grows right on the root surface (the rhizoplane), are preferentially associated with grasses (Hubbell & Haskins 1984).

With respect to symbiotic nitrogen fixation, the only native symbiotic nitrogen fixer that survives sporadically on

the barrens is the actinorhizal shrub known as sweet fern. Following liming, sweet fern spreads rapidly. Unfortunately, the native alders (speckled alder - *Alnus rugosa*, and green alder - *A. crispa*) do not readily volunteer on treated land, despite their winged propagules. A native actinorhizal shrub from Manitoulin Island, soapberry (*Shepherdia canadensis*), has been successfully transplanted onto revegetated barrens, where it produces fruits, but does not so far show evidence of spreading. Another Manitoulin Island species, bearberry (*Arctostaphylos uva-ursi*), has not only been established succesfully by transplant, but is spreading vigorously by vegetative growth and, to a limited extent, by seed. Although not confirmed, this species is suspected of being actinorhizal (Sprent 1979).

In view of the lack of appropriate native symbiotic nitrogen fixers, two herbaceous legumnious species are used as part of the revegetation seed-mixture: Alsike clover (*Trifolium hybridum*) and birdsfoot trefoil (*Lotus corniculatus*). Blundon (1976) compared nodulation of two species of *Trifolium* on limed and unlimed barren soils. She found that nodulation did not occur on unlimed soils, but that liming increased nodulation to 20%. In general, nodulation of Alsike clover and birdsfoot trefoil on revegetated land is excellent. In more difficult sites, such as the boulder clay "badlands" mentioned above, a small leguminous tree native to the Appalachians, black locust, is used with great success.

Nitrogen is not the only plant nutrient for which the soil microbiota play an important role. It is not, therefore, surprising that mycorrhizal associations can be quite critical to the recolonization of disturbed lands, as shown by Schramm (1966) on anthracite wastes in Pennsylvania, and it is likely that V-A mycorrhizal associations, especially if in combination with rhizobial associations, can assist in the accelerated rehabilitation of industrial wastelands (Daft & Hacskaylo 1976, Khan 1978). Indeed, Daft & Nicolson (1969) have suggested that vesicular-arbuscular (V-A) mycorrhiza may have evolved as a response to the need for more efficient extraction of phosphorus. Furthermore, V-A mycorrhizal fungi are not only important in the phosphorus nutrition of the host plant, but they also play a role in soil aggregation, and McIlveen (Balsillie *et al.* 1978) showed that the aggregation of soil particles less than 0.05 mm diameter into particles greater than 0.05 mm in diameter was reduced by 20% in the vicinity of the Sudbury area smelters at a time when no plants (and therefore no V-A mycorrhizae) were present.

Although McIlveen (Balsillie *et al.* 1978) showed a decrease in the numbers of soil fungi and bacteria in the vicinity of the smelters, as well as a restriction in the degree of colonization of roots of oxeye daisy (*Chrysanthemum leucanthemum*) and devil's paintbrush (*Hieracium aurantiacum*) by V-A fungi, some degree of infection with V-A mycorrhizae is almost universal in the plants colonizing the Sudbury barrens, and Blundon (1976) has found that grasses invading barren soils in the Sudbury area readily become V-A infected.

It therefore seems likely that V-A mycorrhizae can re-establish quickly on a relatively sterile substrate through the transport of spores into the area by wind, rain, animals etc., so that the inoculum is not a limiting factor in the revegetation of Sudbury soils, but it is clearly advantageous to have a ready-made inoculum in the soil, and part of the rationale of the transplantation of blocks of soil from target plant communities onto revegetated Sudbury barrens is the introduction of the appropriate symbionts. Indeed, Reeves *et al.* (1979) have found that mycorrhizae are frequently absent in the early stages of succession on disturbed sites, and they hypothesized that the provision of mycorrhizal inoculum might enable the succession to "skip" one or more stages.

Ectotrophic mycorrhizae almost certainly play a role in the survival and colonization of woody species on the barrens. Jones & Hutchinson (1986) have shown that mycorrhizal paper birch seedlings grow better than non-mycorrhizal seedlings when subjected to toxic levels of nickel, and that seedlings infected with *Scleroderma flavidum* grow better than those infected with three different species of *Laccaria*. On the other hand, growth of mycorrhizal seedling exposed to toxic copper levels was significantly less than that of non-mycorrhizal seedlings.

Soil fauna play an important role in litter decomposition and nutrient cycling (Hutson 1980), and they may become critical elements in the reestablishment of a functioning ecosystem on mined land. In the acid, metal-contaminated soils of the Sudbury region, Behan-Pelletier & Winterhalder (unpublished manuscript) found only three oribatid mite species on barren soils, but this increased to thirteen species a few years following revegetation. Semi-barren soils,

with intermediate pH and copper and nickel levels, supported thirty-three species of oribatid, but still far fewer than in undisturbed Ontario forests. Although the fauna of the semi-barren communities that surround the barrens form a source of immigrant mites for the revegetated barrens, there would be some benefit in using the "nucleation" approach, discussed above, as an additional source both of soil fauna and soil microflora.

Although comparisons have not, as yet, been made between the ground beetles of barren and revegetated land in Sudbury, a preliminary study (Winterhalder & Goulet, unpublished data[2]), shows that recently revegetated land supports forty-six species of ground beetle.

PLANT-BASED LIMITING FACTORS

Differential Metal Tolerance of Plants

The degree of metal tolerance itself can be regarded as a limiting variable, interacting as it does with the degree of toxicity of the soil. Dansereau's (1966) 9th "Law of Ecology", the "Law of Ecesis", suggests that "the resources of an occupied environment will first be exploited by organisms with high tolerance and generally with low requirements". Since the initiation of atmospheric improvement in 1972, a number of species or ecotypes of species having these characteristics have begun to colonize previously barren soils, the first noted being *Agrostis scabra* (tickle grass), which was seen to colonize experimental plots that had been fertilized but not limed, a treatment that was not an adequate detoxifier for the purpose of establishing agronomic grasses (Winterhalder 1974). Although tickle grass still colonizes large expanses of moist valley-bottom soil, it is only a weak perennial, and it often does not persist. Tickle Grass was later found to have evolved metal-tolerance (Archambault 1991).

The most notable of the colonizing grasses is tufted hairgrass (*Deschampsia caespitosa*), shown by Cox & Hutchinson (1980) to be multiple-metal-tolerant. An interesting and unique consequence of the dual phenomena of persistence of "relicts" and metal tolerance of grasses is a "savanna woodland" of clonal trembling aspen with an understory of tufted hairgrass that can be found in the Coniston Creek valley.

Other species in which enhanced metal tolerance has been reported are redtop (Hogan *et al.* 1977), Canada bluegrass - *Poa compressa* (Rauser & Winterhalder 1985) and a shrub known as dwarf birch -*Betula pumila* var. *glandulifera* (Roshon 1988).

It is notable that both tufted hairgrass and dwarf birch continue to spread aggressively after the soil has been limed, even if it is also seeded with grasses. This may be explained by the fact that neither species is a true acidophile, dwarf birch being characteristic of fens rather than bogs, and tufted hairgrass normally being found on circumneutral or alkaline soils. In contrast, a known acidophile that occasionally colonizes barren soils, but one upon which no tests of metal tolerance have so far been carried out, is sheep sorrel (*Rumex acetosella*).

Barren peatlands near the Coniston smelter have shown extensive colonization from the edges, with a rush (*Juncus brevicaudatus*), wool sedge (*Scirpus cyperinus*) and rattlesnake grass (*Glyceria canadensis*) being the major colonizers. All of these species should be investigated for enhanced metal-tolerance, as should the dryland sedge *Carex aenea*, which colonizes moderately contaminated soils.

Following colonization by species that are clearly outstanding in their metal-tolerance, we find a second set of plants that are able to colonize those acid, metal-contaminated soils that have spent a number of years free of atmospheric pollutant input, and have shown a consequent rise in pH of at least one unit since the early 1970s. Such soils are found close to the Coniston smelter, and they are currently undergoing colonization by white birch. So far there

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is no evidence that, like dwarf birch, this species possesses metal-tolerant ecotypes, and it is likely that its ability to colonize these moderately toxic soils is the result of the phenotypic plasticity of the species. Another colonist that probably does not involve genetic selection for metal tolerance is wavy hairgrass, which is beginning to move in to form an understory under the relict and newly-colonized white birches. A preliminary study (Archambault 1989) did not show any difference in copper and nickel tolerance between plants from the Sudbury barrens and those at Wawa, where copper and nickel levels are not elevated, although the soil is acidified. It is therefore suggested that its ability to colonize may once again be due to phenotypic plasticity and to its well-known acidophily (Scurfield 1954).

The ability of a species to survive as a relict specimen does not necessarily indicate tolerance at the seedling stage, although it may give the species a head start in terms of colonization following soil amelioration. Amongst the tree species, red oak, red maple, white birch and trembling aspen are the commonest relicts. The survival of the trempling aspen is probably largely due to its ability to form root suckers, the relicts usually occurring as clonal patches on lowland sites, rather than as individuals, and they do not display conspicuous foliar symptoms of stress. They produce copious seeds, but the seeds do not germinate unless the soil is limed.

White birch relicts, on the other hand, occur as coppiced individuals that show a mid-season marginal chlorosis of the earlier leaves, although the leaves that are produced late in the season are green and do not show premature chlorosis. A possible explanation of this phenomenon could be soil moisture stress when the soil is still cold, or calcium-magnesium imbalance, as discussed earlier.

The relict red maples show distinct foliar symptoms of stress in the form of premature reddening, and each coppiced individual undergoes progressive "regressive dieback", in which less and less leaf biomass is produced each year. Each of the stems surrounding the base or "stool" eventually dies, and is replaced by a smaller stem. Ultimately all meristematic sites for suckering are used up, and the individual dies. Individuals continue to produce seeds throughout this prolonged period of dieback, and the seeds germinate normally, but quickly develop a red coloration and do not progress beyond the first foliar-leaf stage. The interaction of the red maple seedling with the soil is clearly very different from that which occurs in the case of white birch. There is some evidence of partial recovery of regressing maples following liming, but evidence is not conclusive. As mentioned previously, there is also some preliminary evidence that magnesium deficiency (or magnesium-calcium imbalance) may be a factor in the decline of red maple, but other possible causes such as lack of mycorrhizal infection require attention.

Competition as a Limiting Factor

Although it would be incongruous to consider plant competition as a potential limiting factor in the revegetation of bare soil, it must be considered as a factor once revegetation measures such as seeding or tree-planting have been employed. Competition, usually from grasses, can form a barrier to colonization and succession on many reclamation sites, as well as competing with planted trees for light and nutrients (Bradshaw & Chadwick, 1980), and forming a winter habitat for bark-gnawing rodents. In the Sudbury land reclamation program, the use of low seed and fertilizer rates, probably assisted by the stony soil, seems to have eliminated the competition factor.

A striking example of the need to consider the relative merits of seeding and natural colonization with care is seen at Mount St. Helen's. Immediately after the eruption in 1980, the Soil Conservation Service aerial-seeded 32,000 hectares with non-native grass and legume seeds, in an attempt to stabilize the surface. Unfortunately, the grass cover did little to prevent erosion, but attracted mice that killed many of the existing conifers by chewing the bark during the winter (Dale 1992). Furthermore, the dense cover of birdsfoot trefoil helped to reduce the success of native species. Following the Mount St. Helen's experience, the Soil Conservation Service has established native plant nurseries to provide seeds of native species.

Microclimatic Factors

As part of the Laurentian University-Department of Lands & Forests SEEP study, a comparison was made in 1969-70 of the microclimate on an open barren site near Coniston and an open scrub oak forest near Falconbridge. Surface wind velocities on the barrens were approximately twice those in the woodland, and they had a beneficial cooling effect on surface soil temperatures. On the bare, open patches within the scrub forest, temperatures exceeded the thermal death point (about 47°C) on several days in the early summer.

Courtin[3] (personal communication) has suggested that the slowness with which vegetation cover is spreading onto the barren areas between the birches of the semi-barren communities is due to a microclimate effect. While frost action is extreme in the barren areas, the area under each tree forms an "oasis" by virtue of the insulating effects of the leaf litter.

Seed Availability Factors

On the Sudbury barrens, there appears to be small resident seed bank, but most of the seed source is from the seed rain. This is in contrast to the situation described by Archibold (1978), who studied similar barrens created by the smelting of sulphide ore in Trail, British Columbia. He concluded that the limiting factor to recolonization at Trail was lack of seed rain, and he demonstrated this by soil-tray experiments (personal communication[4]). Trays filled with sterilized potting soil were countersunk into the barren soil surface, but no native species grew when the trays were returned to the greenhouse, although several tree and shrub species with wind-dispersed seeds were present within reasonable distance of barren soils (e.g. trembling aspen, *Salix scouleriana*, white birch). However, the present author's experience with such seed trays in the Sudbury area (unpublished data) suggests that they are a poor indicator of seed rain compared to the technique that utilizes limed plots of native soil, as described by Winterhalder (1983). The difference between the two sites may have had something to do with climatic or microclimatic factors, or else were a reflection of the technique used.

Both the limed plot approach and seed traps consisting of paper plates covered with sticky Tree Tanglefoot have demonstrated that there is a significant seed rain on the Sudbury barrens. However, the seeds trapped are normally of light, wind-dispersed species, and it is to be expected that species with larger, heavier seeds will be slower to colonize, even when the soil is no longer toxic. An exception is seen in the case of the bird-dispersed blueberry, which readily colonizes limed land and, more recently, unlimed land. Also, occasional red and white pine seedlings can be found on barren land, some distance from the nearest seed source; in this case the means of seed transportation is as yet unknown.

The collection of native seed was carried out in 1978 as part of the Regional Municipality of Sudbury's Land Reclamation Program, but was discontinued since it was considered by the RMS to be uneconomical. There were certainly some beneficial results, especially with respect to wavy hairgrass, in that it was possible to introduce this grass in advance of its normal associate, white birch, which colonized immediately following treatment. In general, however, most of the more easily-collected and -sown species are able to colonize naturally without assistance.

One method of decreasing the limiting nature of the seed rain is by the transplanting of sods of soil and plants from natural communities, so that the plants can act as a seed source. The use of sods also introduces a small seed bank. Glass (1989), in his review of the role of seed banks in restoration and mangement, points out that the seed bank in a plant community often shows a lack of close correspondence to the above-ground vegetation, and may contain species from earlier stages in succession. The use of some soil from a plant community that is the **climax** for the area, in the form of sod transplants, is therefore highly desirable.

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This method of exploiting natural tendencies towards spontaneous colonization is a modification of the principle of "nucleation". In their study of the Grand Bend sand dunes on Lake Huron, Yarranton & Morrison (1974) noticed that individuals of certain pioneer species such as *Juniperus virginiana* (red cedar) formed nuclei for the initiation of patches of other "persistent" species that spread and eventually coalesced. Miller (1978) suggested that such an approach might be taken in revegetation, in that selected "pioneer" species could be planted in clumps, then the "persistent" species introduced into the clumps once the pioneers are well established.

The modification of this approach which is under investigation on the revegetated Sudbury barrens at this time emphasizes the introduction of understory species characteristic of the plant community targetted. The pioneer species are introduced in large blocks of their own soil, so that seedlings or propagules of associated species are introduced with them.

Sometimes the selection of species that appears as a result of this approach is quite surprising, and plants introduced through the transplantation of soapberry and bearberry include *Juniperus communis* (juniper), *Picea glauca* (white spruce), *Fragaria virginiana* (wild strawberry), *Satureja vulgaris* (wild basil), *Senecio pauperculus* (balsam ragwort), *Smilacina stellata* (starry false Solomon's seal) and several species of *Aster* (asters) and *Solidago* (goldenrods).

THE IMPORTANCE OF TIMING AS A LIMITING FACTOR

The complexity of the interacting group of factors that control colonization is well illustrated by considering the establishment of one of the more important woody colonists, the trembling aspen. Once the seeds are ripened, the first constraint arises from the relatively short longevity of poplar seeds under natural conditions (Young & Young 1992). The seeds have to be dispersed to what Harper (1977) calls a "safe site", at which the seeds can germinate and seedlings can establish, while they are still viable. Wind direction and force will be important in carrying the seeds, and so will the presence of some turbulence in depositing them. Upon reaching the site, the correct surface conditions will be necessary for germination, including a fairly open plant cover like that seen in the first spring following treatment. If insufficient moisture is present during the short viability period, there will be no seedling establishment. For this reason, areas treated in different years may end up with very different patterns and densities of woody plant cover, despite similar overall conditions.

THE HOLOCOENOTIC ACTION OF POTENTIALLY LIMITING FACTORS

It is important to realise that environmental factors do not act independently, but interact, often involving positive or negative feedbacks. While it is not possible to show these interactions schematically, an attempt has been made (Winterhalder 1984) to show that a number of different factors are responsible for the Sudbury barrens (Figure 6).

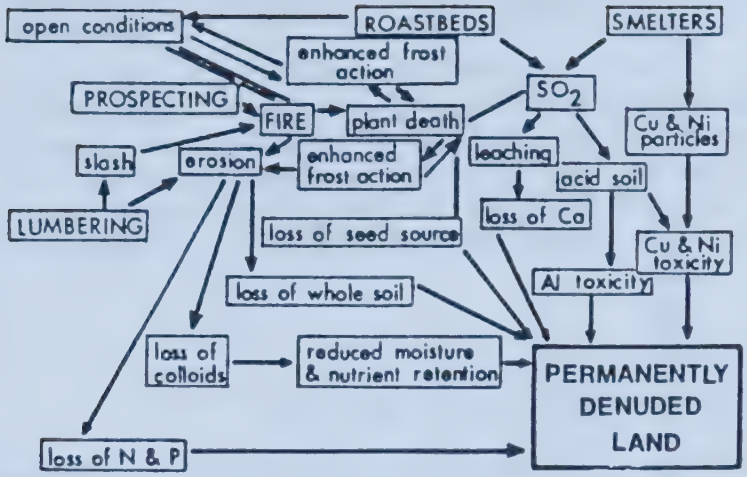

Figure 6: *A simplified representation of some of the major factor interactions leading to the formation of barren land.*

BREAKING THE CYCLE - THE TRIGGER FACTOR CONCEPT

The simple act of surface-applying ground dolomitic limestone creates positive feedback loops throughout the system. In fact, the Sudbury Regional Land Reclamation Program is an excellent example of the use of minimal amelioration as a "trigger factor" (Winterhalder, 1983), or what Skaller (1981) calls "minimal intervention". It was first noted by Winterhalder (1974), that minimal treatment of acid, copper- and nickel-contaminated soils in the Sudbury area led to rapid colonization, in which tickle grass seedlings became established after ameliorating the soil either with fertilizer or with limestone. Later, the role of manual surface liming of these soils in initiating colonization became known as a "trigger factor" (Winterhalder, 1983).

Hedin & Hedin (1990) and Hedin (1992) have described a very similar phenomenon on coal strip-mine spoils in Pennsylvania, where the surface application of limestone, fertilizer and wood chips stimulates the establishment of trembling aspen seedlings. Hedin (1992) refers to this phenomenon as the elimination of a "colonization bottleneck".

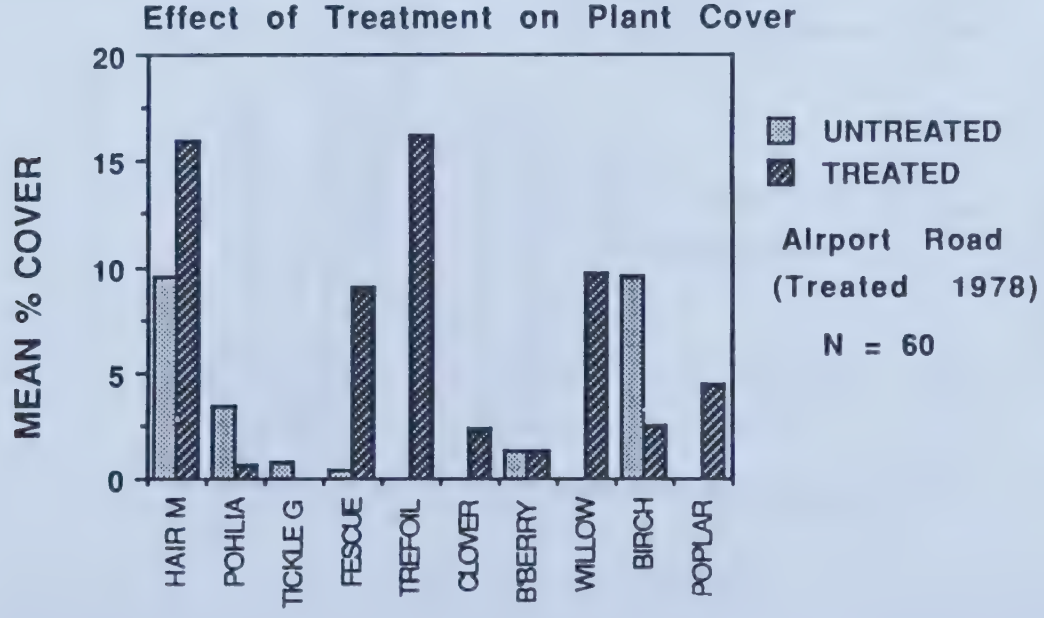

Figure 7: *Distribution of plants in relation to soil pH, 14 years after treatment.*

When limestone is applied manually from a bag, it is inevitable that it will be distributed in a patchy fashion, so to some extent a mosaic ensues, in which the degree of liming varies from zero to optimal or even excessive. This is probably beneficial, since it leads to a more random spacing of plants than an even cover would, as well as creating an environmental mosaic that will favour diversity both in terms of species and genetic biotypes. Some preliminary studies have indicated that a certain amount of selection of species with respect to pH has already occurred (Figure 7).

FACTORS CONTROLLING THE DYNAMIC PATH - THE INFLUENCE OF THE TYPE OR TREATMENT APPLIED

The process of "succession" on barren lands can follow one of three different routes, depending on whether the barrens are left untreated, treated with limestone only, or treated with limestone and a grass-legume seed mixture.

When left untreated, colonization is by metal-tolerant plants such as tufted hair grass, tickle grass and dwarf birch, although in the vicinity of the Coniston smelter, which has been inactive for 20 years, white birch is currently showing vigorous colonization and growth.

The importance of the dynamic processes that can occur following treatment was first appreciated in 1974 when a three-hectare sandy barren site in the Coniston Creek valley was grassed with Canada bluegrass, which is rhizomatous and forms an open sward. Within a year, there was noticeable colonization by other grass species such as redtop, legumes such as cow vetch (*Vicia cracca*), native "wildflower" species such as pearly everlasting (*Anaphalis margaritacea*) and woody species like trembling aspen.

The different dynamic path taken by the vegetation on adjacent areas, and the distinct line that demarcates treated and untreated areas, can be illustrated by a site west of Coniston, where a transect from untreated to limed-only shows the initiation of shrub growth on the limed side, with a much stronger stimulation of the native nitrogen-fixing sweet fern than of willow (Figure 8), presumably due to the sweet fern's ability to fix its own nitrogen. In Figure 9, however, it is interesting to note that, whereas poplar and willow establishment are stimulated by liming, the reverse is true of white birch, probably due to the competitive disadvantage at which the poplar and willow place the birch.

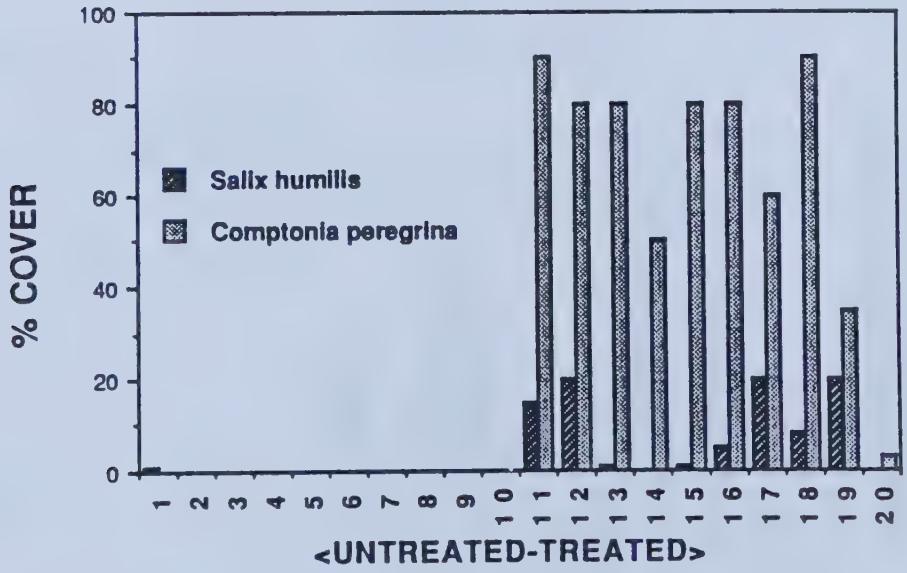

Figure 8: *Transect across liming boundary west of Coniston.*

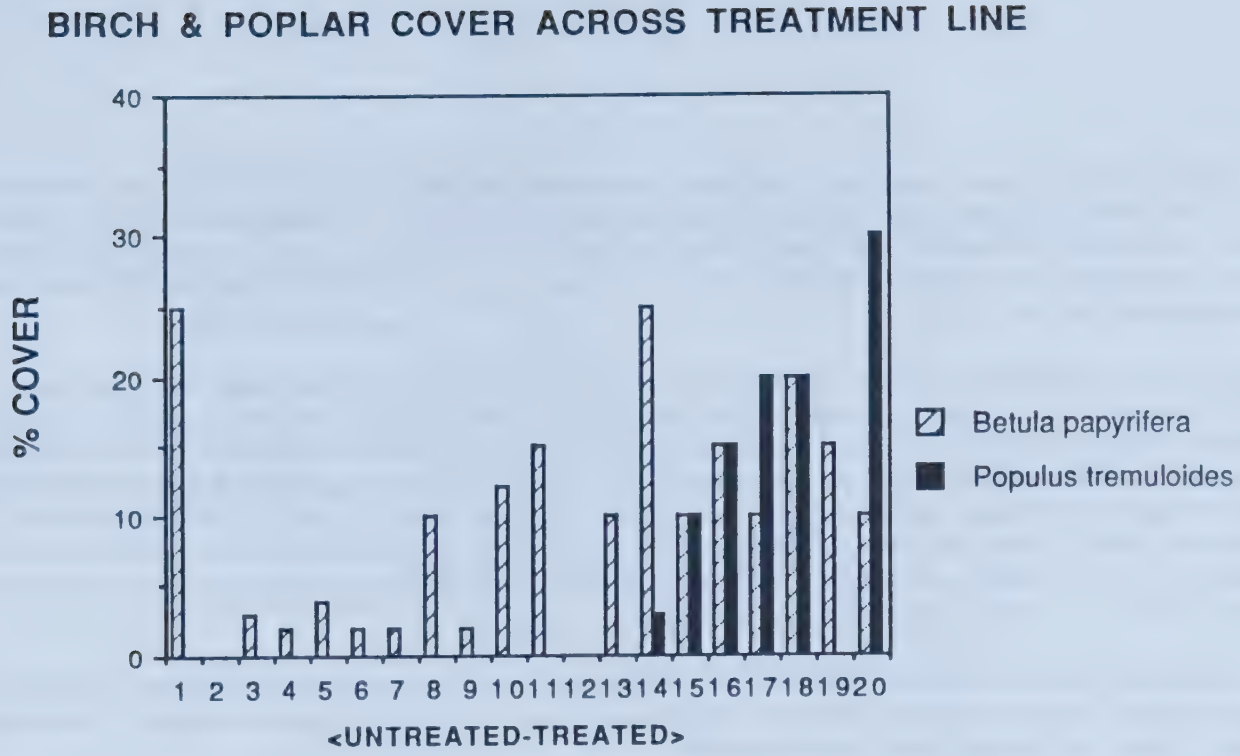

Figure 9: *Transect across liming boundary northwest of Falconbridge.*

As a result of the trigger factor effect described earlier, it is not necessary to use a grass-legume seed mixture to achieve revegetation following liming, and the seed rain is a sufficient source of seeds to achieve a good cover of birch, polar and willows within a few years. At a site near Hannah Lake, one area was limed, fertilized and seeded, while the other was limed only. Whereas the seeded area showed modest colonization by wood species, that of the limed site was much more extensive (Figure 10).

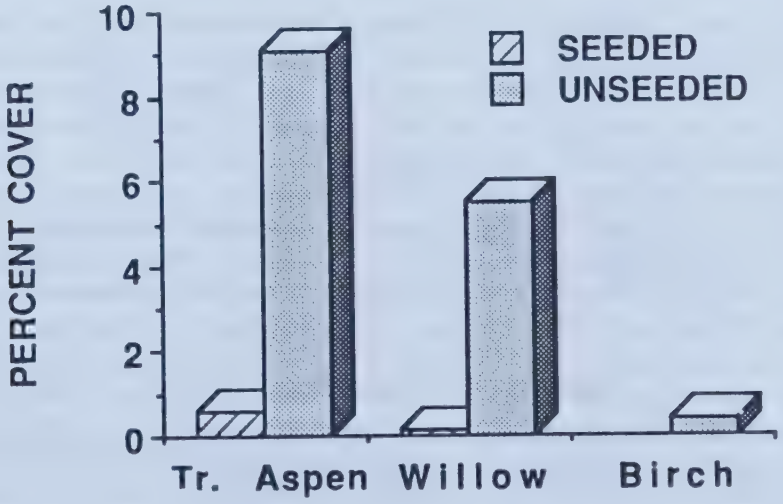

Figure 10: *Percent cover of woody plant seedlings on seeded and unseeded plots.*

It could be argued that the use of a seed mixture, and the concomitant introduction of alien species, is neither necessary nor desirable. Nevertheless, there are at least three advantages to the use of a seeding step. Firstly, there is a very rapid establishment of plant cover, which not only stabilizes erosion-prone sites, but also gives an

immediate aesthetic improvement that is gratifying to operational and funding agencies. Secondly, the introduction of a nitrogen-fixing legume is clearly benefical to the mineral nutrient status of the developing ecosystem. Thirdly, the woody species develop in a more patchy fashion on the seeded sites, giving rise to the spatial diversity that is both ecologically and aesthetically desirable, whereas on unseeded sites the woody plants tend to form dense, homogeneous thickets.

Despite the three different colonization trajectories that occur between untreated land, limed and seeded land, and limed-only land, it is interesting to note that the type of liming material and/or fertilizer (if any) that is used on limed and seeded sites has little effect on colonization. Indeed, variations in seeding rates and even in species composition of the seed mixture do little to influence the process of colonization, although it seems inevitable that the presence of leguminous species in the mixture will have a long-term effect on the structure and function of the plant-soil system. Indeed, the use of black locust in some sites may also influence colonization, since there are frequent reports of black locust stands providing a favourable environment for colonization by other woody species (e.g. Ashby *et al.* 1980, in Indiana, Missouri and Kansas).

As shown in Figure 11, there is a tendency for the importance of introduced species to decrease and of native species to increase with time after treatment. The pattern shown by nitrogen-fixing birdsfoot trefoil is interesting, since it peaks, then falls off as the canopy develops.

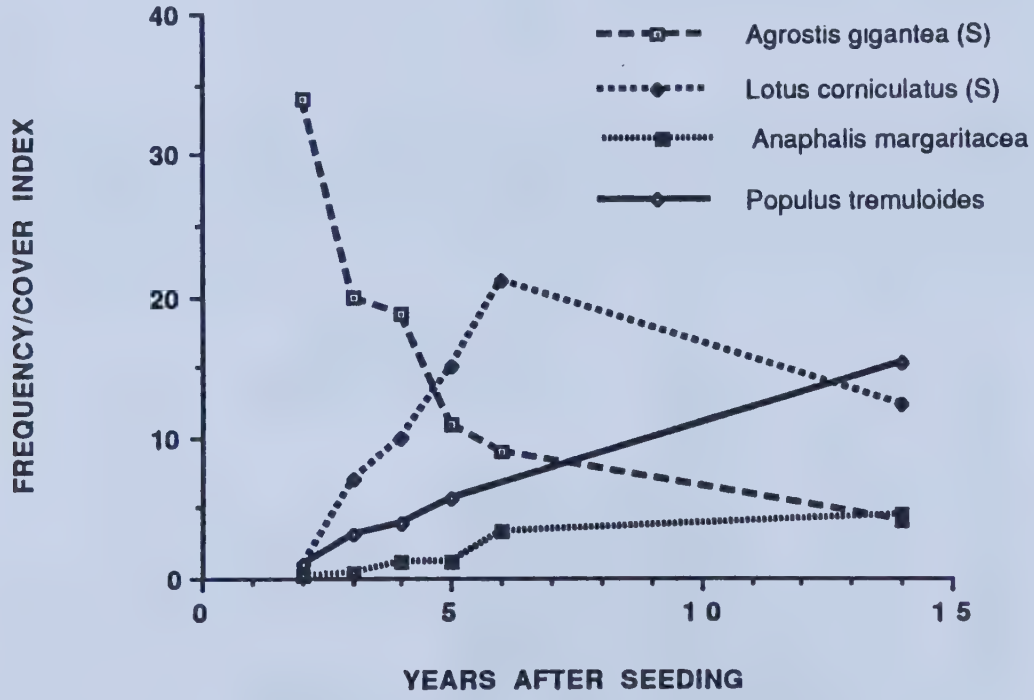

Figure 11: *Change in Cover/Frequency Index of four species (two seeded, two volunteer) over fourteen years following reclamation of acid, metal-contaminated Sudbury soils.*

Figure 12, showing the relative importance of the "top ten" species, illustrates the fact that the plant community that results from the revegetation procedure contains components derived from the seed mixture, the seed rain and any metal-tolerant plants already on site. Even planted woody species can have an effect on later colonization.

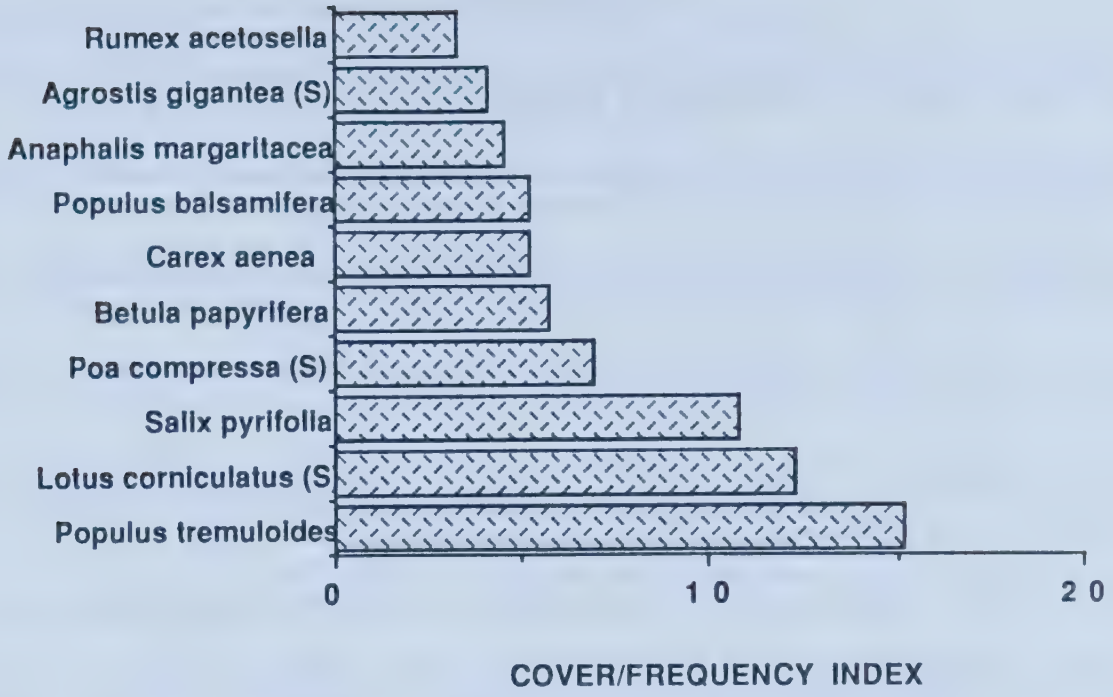

Figure 12: *The "top ten" species in terms of Cover-Frequency Index after ten to fourteen years. (Species labelled (S) are derived from the seed mixture).*

SUCCESSIONAL REVEGETATION AND THE "NURSE CROP" EFFECT

Seeding or planting and natural colonization or "succession" are by no means mutually exclusive. The whole concept of the "nurse crop", widely used in revegetation, is based on the idea of one species facilitating the establishment of another more desirable and usually longer-lived one (the Relay Floristics model of succession). It is traditional in northern Ontario to use a cereal species such as fall rye (*Secale cereale*) as a nurse crop (Peters 1984), but on the Sudbury barrens, this has been found unnecessary, partly because of the presence of a stony mantle on most sites, which acts as a seed trap. The most commonly touted function of the nurse crop is microenvironmental improvement, with reduction of evapotranspiration and increased snow cover in cold climates as examples of benefits. However, another benefit of a nurse crop, so long as the cover is not too dense, is its function as a seed trap. On uranium mine tailings in Elliott Lake, Ontario, Kalin & Smith (1984) have shown that the spontaneous establishment of white birch and trembling aspen has only occurred where there is some grass cover. While it is possible that both grasses and trees may be kept out of other sites by soil properties, it is almost certain that the grass has played a role in trapping the wind-blown seeds of the two tree species. On the Sudbury barrens, the primary factor facilitating colonization following liming is soil detoxification, but the seed rain is made more effective by the presence of a herbaceous cover that creates turbulent air flow over the surface, leading to the deposition and trapping of seeds. Colonization by woody plants is therefore assisted in a number of ways by the presence of the cover introduced by seeding, and the grass-legume cover can thus be interpreted as a nurse crop in relation to the native colonizing species.

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ENVIRONMENTAL INITIATIVES AND LANDSCAPE REHABILITATION TECHNIQUES AT THE SUDBURY, ONTARIO OPERATIONS OF INCO LIMITED

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ABSTRACT

Inco Limited is one of the world's premier mining and metals companies. It is a leading producer of nickel and a major producer of copper, precious metals, cobalt and high-nickel and other allows. A corporate commitment to sustainable development and the environment and community cooperation have resulted in progressive landscape rehabilitation and ecosystem development in the Sudbury area.

A major environmental focus, to further reduce SO2 emissions, is the sulphur dioxide abatement project which involved major technological changes in milling and smelting. In 1994, the SO2 emission rate will be 265 kilotonnes per year, 90% of the sulfur in the Sudbury ores will be contained and not emitted (compare with a containment rate of about 70% before the project began). The Company maintains extensive programs to monitor air, water and effluent quality. Other environmental initiatives include the development of plans for the decommissioning of active and abandoned mine and plant sites, the preparation of rehabilitation plans, establishing emission inventories, research into acid rock drainage, groundwater monitoring, waste management and recycling.

Soil conditions provide unique challenges to reclamation and revegetation in the Sudbury area. With soil erosion that occurred as a result of historical limbering activities, primitive smelting techniques at the turn of the last century and forest fires, soils tend to be acidic, in shallow pockets over bedrock, lacking in nutrients and with limited water holding capacity. Soil also contains elevated levels of metals and in susceptible to enhanced frost action. Surface reflective temperatures are high. For large expanses of stressed land, suitable seed sources of native plant materials are limited. Climatic considerations in the area are also an important factor with respect to vegetation establishment.

Man's activities and the subsequent ecological disturbances had a significant impact on an estimated 10,000 ha in the Sudbury area. Overall, 40 to 50% of the impacted areas in the region have been reclaimed and significantly improved and over 2 million trees have been planted in a cooperative venture involving government, private industry, academic institutions and the private sector.

Inco Limited's rehabilitation of tailings areas and industrially-stressed lands involve innovative techniques such as surface stabilization of tailing with straw, species introduction (for example, nitrogen-fixing woody legumes), underground forestry seedling crop production and the aerial lime treatment and seeding program. Benefits of these rehabilitation efforts include aesthetic enhancement of the area, the successful development of ecosystems and wildlife habitats, improvements in the quality of surface water runoff and prevention of further soil erosion.

Future rehabilitation activity will involve ongoing progressive decommissioning, the promotion of vegetation establishment and species diversification, development of wildlife and fish habitats and examining the impact of revegetation of watersheds on water quality and quantity.

Investigations are ongoing to promote safe, productive and economically feasible techniques for environmental rehabilitation.

HETEROTROPHIC BACTERIA AND GRASS COVERS ON FRESH, BASE METAL TAILINGS

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ABSTRACT

Acid mine drainage (AMD) resulting from the oxidation of base metal tailings represents a substantial environmental liability for the Mining Industry.

A reduction in the rate of acid generation is suggested through the establishment of an oxygen consuming bacterial population. Heterotrophs, which decompose organic matter provided by a vegetation cover, would outcompete oxidizing bacteria for oxygen consumption.

Experiments have been carried out to test for the presence of heterotrophs in fresh tailings. Methods have been developed which allow for germination of grass seeds on fresh tailings. Roughening of the tailings surface and an organic supplement were found to greatly assist in vegetation establishment.

The experiments have demonstrated that it is possible to vegetate fresh tailings. Heterotrophic bacteria are numerous in the root zone. Further work is now required to establish the quantities of nutrients supplied to the heterotrophs in the root zone and to produce a moisture containing and acid neutralizing layer for acid water generated in the deeper parts of the tailings.

Introduction

A reduction of the acid generation rates in tailings is expected if the movement of water and oxygen through the tailings mass can be prevented. Placing a cover over the tailings or submerging them under water are current practices of tailings disposal. An oxygen-consuming living cover over tailings is proposed, through the incorporation of oxygen-consuming bacteria into the root zone of vegetation growing on fresh tailings.

Tailings, when leaving the mill, are generally alkaline, but may generate acid very quickly. Revegetation is normally carried out after the tailings surfaces have dried sufficiently for heavy equipment to traverse. However, during this period of de-watering, acid-generation in the tailings usually proceeds, consuming the alkalinity supplied by the mill. Agricultural limestone is used to neutralize the surface prior to seeding. Acid generation proceeds underneath a typical vegetation cover, as the root region does not provide a barrier to oxygen and water. Although a vegetation cover will reduce runoff and increase evapotranspiration, water still enters the tailings mass.

A reduction in the rate at which tailings oxidize might be achieved if a population of oxygen-consuming bacteria (heterotrophs) could be maintained in the root region of a vegetation cover. Heterotrophs growing in the root region of a vegetation cover, would consume the oxygen in the water entering the tailings. Such bacteria have much higher potential growth rates than chemo-autotrophs, such as the pyrite oxidizing bacteria (*Thiobacillus* spp). Thus, if oxygen is a limiting factor in the acid generation rates, then depletion of oxygen in the pore water would reduce that activity of oxidizing bacteria.

Although the concept of an oxygen consuming cover on fresh tailings is attractive, the feasibility is dependant on

a) the presence of heterotrophs in fresh tailings, b) the ability of establishing a vegetation cover on fresh tailings with root penetration, and c) the productivity of such a vegetation cover to sustain the heterotrophic activity.

This paper summarizes the findings of field and laboratory experiments where fresh tailings were used to establish vegetation and determine the presence/absence of heterotrophs and thiobacilli in the root region.

Materials and Methods

Fresh tailings were supplied from a base metal mine producing Zn and Cu. Alkalinity and pH were determined on slurries of 1:1 (volume:volume) of tailings and distilled water using standard methods (ASTM, Method 2310). The pH of the slurries and water were determined using an Orion pH meter with a combination electrode.

Determination of heterotrophs and Thiobacilli: Enumeration of heterotrophic bacteria was achieved by plating 1 mL aliquots of tailings slurries (5 mL distilled water: 5 g tailings or dilutions thereof) on Petrifilm plates (3M Corp.). The plates were incubated at room temperature, and the number of colonies counted after 1, 2, and 4 weeks.

Thiobacilli were enumerated through serial dilution in the medium of McCready et al (1986). Ferrous sulphate was added to the medium, which when oxidized to ferric sulphate produced an orange colour in the medium. The tubes were incubated at room temperature. Presence or absence of thiobacilli were noted, based on the colour of culture medium after incubation for 40 days .

Vegetation establishment on fresh tailings: Plastic garden pots (15 cm diam.) were filled with fresh tailings. Six pots were set up with each of the following treatments: 1) Tailings vegetation + fertilizer; 2) Tailings vegetation + fertilizer + molasses; 3) Tailings only; 4) Tailings + molasses; 5) Tailings + grass seed + fertilizer; 6) Tailings + grass seed + fertilizer + molasses.

Molasses containing 50 % (w:v) sugar was added as a carbon amendment for heterotrophic bacteria, at a rate of 8 mL/pot, resulting in an equivalent of 10 g sugar/L of tailings. Slow release fertilizer (Osmocote 19:6:12) was added at 1.3 g/pot to enhance grass and bacterial growth. The grass seed (White Rose, Lawn Pleasure) was added at a rate of 0.5 g/pot.

Pots were grown under banks of fluorescent lights with a 12:12 day:night light regimen in the laboratory. They were watered daily (distilled water) to keep them moist. After 6 weeks of growth, the pots were harvested. Above ground biomass was cut off with scissors, dried at 105°C, and weighed. Bacterial counts (aerobic heterotrophs and thiobacilli) were made.

Tailings surface conditions: An experiment was set up to investigate the effect of surface treatments on seed germination and vegetation establishment on fresh tailings.
Four 50 x 50 cm plywood boxes were constructed, and filled to a depth of about 15 cm with fresh tailings. A chamber with a width of about 10 cm allowed the maintenance of a water level in the lower part of the tailings mass. Decant water from the original tailings barrel was added to the boxes. The boxes were left to settle. Surface treatments, fertilizer and seed were added 5 days later.

Each box was subdivided into the following plots: 1) tailings only; grass seed sown over half the surface; 2) surface roughened; 3) surface roughened + Hydrosource; 4) Verdyol; 5) wood chips; 6) surface roughened + wood chips. Plots were 10 x 20 cm.

Molasses was added to 1 box before it was subdivided into plots. The molasses was mixed with tailings at a rate of 4 mL/L before the tailings were added to the box. This represented half of the application rate to the pot experiment.

Surface roughening was applied by scratching the surface with a nail (3.5 mm in diameter) to a depth of 1 cm, or by adding amendments. Scratches were 2 cm apart. Organic material used in the plots were wood chips, hydrosource, and Verdyol. Wood chips were applied to give a layer approximately 1 cm thick. Hydrosource was also used to provide a moist environment for seed germination. Hydrosource is a polyacrylamide gel which absorbs many times its own volume in water. Verdyol mats, provided cover for the tailings, reducing moisture loss.

Osmocote 19:6:12 slow-release fertilizer was applied to all of the boxes at a rate of 723.7 $g.m^{-2}$. Grass seed was applied at a rate of 280 $g.m^{-2}$.

Field experiments: Field trials were carried out on fresh tailings. A plot 70 m long by 8 m wide was established in June 1990 over a moisture gradient which existed along the tailings slope (wet, moist, and dry). These Verdyol strips (4.0x 3.75m) were further divided into areas where a) a Verdyol mat cover was placed over the length of the plot, and grass seed sources added on top of the Verdyol mat; b) grass seed sources and amendments were distributed directly on the tailings surface without a Verdyol mad; and c) grass seed sources and amendments were distributed directly on the tailings surface, then a Verdyol mat was placed over the seeded areas.

The tailings were seeded with a combination of common lawn seed supply containing 60% annual rye grass, 30% Timothy grass, and 10% Creeping Fescue and a mixture with 60% Kentucky Bluegrass. The two seed blends were mixed in a 4:1 ratio and the mix was applied at a rate of 27 g/m2 over each of the designated grass plots.

Fertilizer was added to the plots which contained controlled-release, sulphur-coated urea. A dose of 147/g m2 was applied to each of the designated grass plots.

At the end of the second growing season, after regrowth during the winter, three blocks of tailings (35 x 35 cm) were dug to spade depth in each plot containing grass growth. The shoot material was cut off with scissors for dry weight determination. Tailings blocks were cut into two halves. One half was used for separation of tailings from litter and root material.

The material was placed in a sieve and the tailings washed through with a high pressure hose. The litter, shoots, and roots were dried at 105 °C for dry weight determination. Tailings cores were cut from the remaining half blocks. These cores were used for microbiological and chemical studies.

Results

In Table 1, the numbers of heterotrophic bacteria in various tailings samples in the milling circuit and exposed in the tailings pond are shown. It is evident from the results that in the mill, heterotroph numbers are low or below detection limits. However in a sample from the tailings beach, where flotation reagents frequently accumulate, a substantial populations of heterotrophs were found. As the tailings acidify, the populations diminish, as exemplified by the sample taken from the old tailings ponds and a ditch with tailings seepages.

Sample	Heteroprophs (bacteria/mL)	pH
Sagmill before addition	23	6.7
Sagmill after addition	550	7.0
Ballmill discharge	0	7.7

Sample	Heteroprophs (bacteria/mL)	pH
Thickener underflow	0	11.5
Thickener overflow	0	12.5
Barrel tailings-surface	<1	n.d.
Barrel tailings-sub-surface	6	n.d.
Barrel water	3	11.5
Tailings beach	1404000	8.1
Tailings seepage ditch 1	40500	2.1
Tailings seepage ditch 2	10800	4.8
Old Pond	9	2.2

Table 1: *Bacterial counts in tailings*

Vegetation establishment in pots: The results of the bacterial colonisation in the seeded pots is given in Table 2. Counts for total aerobic heterotrophs and thiobacilli were made at harvest after 6 weeks.

The highest numbers of heterotrophs were found in the pots amended with molasses. The lower numbers were found in the unamended pots. This contrasts with the findings for the fresh tailings prior to planting (Table 1), indicating that unamended tailings have the ability to support populations of heterotrophs. There were no thiobacilli found in any of the pot treatments after 6 weeks.

In the presence of molasses, few seeds germinated due to the growth of pathogenic fungi on the tailings surface. Root penetration was poor in all treatments, no more than 1 cm into the fresh tailings. In these conditions, seeds did not germinate well and vegetation establishment was poor. The conditions for seed germination and establishment had to be improved.

Treatment	Heterotrophs (x10 ^5/g tailings)	Thiobacillus (pres +/abs -)
Tailings Only		
T2	143	-
T3	130	-
Tailings/Molasses		
T2	6760	-

Treatment	Heterotrophs (x10 ^5/g tailings)	Thiobacillus (pres +/abs -)
T4	2690	n.d.
Tailings/Seeded Grass		
T5	216	-
T6	115	n.d.
Tailings/Molasses/Grass		
T2	231	-
		(n.d. = not determined)

Table 2: *Pot Experiment - Bacterial Numbers*

Tailings surface treatments for seed germination: In the tailings boxes, were sections of the surfaces were roughed, covered with woodchips , Verdyol and/ or Hydrosources, germination was first observed after 4 days. Measurements were taken on days 6,7,8, and 13 after sowing. Results shown in Table 3 are mean values of the different surface treatments after 13 days. Values from the box which contained tailings mixed with molasses represent single values and not means.

Treatment	No Molasses Seedlings/Box	Molasses Seedlings/Box
Control	51	0
Roughened	194	12
Rough/Hydrosource	125	0
Verdyol	114	37
Wood Chips	134	30
Rough/Wood Chips	132	23

Table 3: *Tailings Box Experiment - Grass Germination*

All surface treatments (roughening, Hydrosource, Verdyol, wood chips) gave better germination rates than untreated controls. Surface roughening gave the highest germination rates. Hydrosource on a roughened surface gave lower germination rates than roughening alone. Germination rates on Verdyol were initially similar to controls (6 days from sowing), but subsequently, rates increased. Treatments with wood chips had higher germination rates than those with surface roughening alone. Very few seeds germinated on molasses-treated tailings, confirming the results of obtained previously in the pots. With these result it was possible to proceed to field trials.

Field experiment: Standing biomass and percent cover were measured on plots 3 months after set up (data not

shown). The Verdyol mats with seed below them or seeded on top of them greatly increased grass vegetation covers, reaching 100% cover in some plots. Grass germinated and established in cracks in the bare tailings, while seeds were washed from flat surfaces. However, where grass did establish, and fertilizer was applied, tall grass clumps developed.

After overwintering, and growing through one more summer season, the plots with 100% healthy grass cover were remeasured. Cores were collected for determination of shoot and root productivity as well as examination of microbial activity, in particular, for the presence or absence of oxidising bacteria in relation to the vegetation.

Shoot and root biomass dry weight data are summarised in Table 4. A well defined root mat, about 1 cm thick, was present under all five plots. Individual roots were found throughout the depth of the cores (i.e. to 20 cm at least). The highest shoot weight was found in plot 1A2, which was located on a Verdyol mat within an areas defined as "wet". The next highest shoot production was in plot IC2, which was classified as "dry". The lowest shoot production came from plot 3B4 which was "moist". This suggests that this apparent moisture gradient did not affect vegetation establishment.

Plot	Moisture	Shoot wt (g/sq.m)	Root/Litter (g/sq.m)	Total biomass (t/ha)
1A2	wet	164.8	682.4	8.47
3B4	moist	25.5	353.3	3.79
1C2	dry	136.8	863.9	10.01
1C4	dry	62.7	352.5	4.15
3C4	dry	99.6	310.1	4.1

Table 4: *Tailings Vegetation Biomass after Second Year*

Verdyol placement, whether on top of, or beneath seeds did not seem to make much difference in grass cover after one growing season. Of the 5 plots with a grass cover from the entire experiment, plots 1A2, 1C2, 1C4 were sown with seeds over Verdyol whereas plots 3B4 3C4 were sown with seeds beneath the Verdyol. In plots without Verdyol the grass cover was absent or poor.

The presence or absence of oxidising bacteria (thiobacilli) and heterotrophs was determined in root/tailings cores taken at a depth of 3 cm and 15 cm below the vegetation plot. The results are summarised in Table 5. Thiobacilli were detected in samples showing clear signs of oxidation (orange colouration) and absent from samples with no orange zones. Thiobacilli were present in all samples except for plot 1A2 at 15 cm, and plot 1C3 at 15 cm.

Sample (depth)	Heterotrophs (bacteria/mL)	Thiobacillus (+/-)	pH	Acidity (mg/L/g)	Alkalinity (mg/L/g)
Control 3 cm	174	+	7.3	310	669
Control 15 cm	1455	+	7.1	298	681
1A2 Wet 3 cm	1380000	+	6.7	263	373

Sample (depth)	Heterotrophs (bacteria/mL)	Thiobacillus (+/-)	pH	Acidity (mg/L/g)	Alkalinity (mg/L/g)
1A2 Wet 15 cm	1270000	-	7.0	224	287
3B4 Moist 3 cm	324000	+	6.3	449	357
3B4 Moist 15 cm	35700	+	6.9	210	294
1C3 Dry 3 cm	1940000	+	6.6	345	356
1C3 Dry 15 cm	62100	-	7.2	160	404

Table 5: *Bacterial Counts in Tailings with Vegetation*

Heterotroph numbers from the same cores give some indication total microbial activity. The largest populations of bacteria were found in a dry plot at 15 cm depth. The next highest numbers were in wet plots (1A2). Heterotroph numbers were generally higher in root zone (3 cm) than deeper in the profile (15 cm), and also higher in vegetated areas than in controls.

Discussion

In order to realize the concept of introducing oxygen consuming bacteria into the root zone of a vegetation cover on fresh tailings, several components had to be established first in laboratory and field experiments. The presence of heterotrophs in the tailings had to be determined and the methods required to establish a vegetation cover with root penetration on relatively fresh tailings had to be developed.

Laboratory and field experiments were initiated to identify conditions necessary for the development of vegetation on fresh mine tailings. Laboratory studies in pots and larger "tailings boxes" led to initial field trials in 1990.

The pot experiment demonstrated that root penetration in settled tailings was a problem. Molasses, while it increased bacterial populations, was highly inhibitory to germination of the seeds. Heterotrophic bacterial populations were similar both with and without vegetation, over the 6 week experiment. Thiobacilli were not detected in any of the pots.

Grass seedlings germinated well in surface-roughened (Verdyol, sawdust of direct surface roughening) tailings. Therefore, a roughening treatment (Verdyol) was appropriate for the field trials.

The field trials demonstrated conclusively that a grass cover can be established on fresh tailings and form a continuous organic layer on the tailings surface. This vegetation cover overwintered, and biomass at the end of the second year exceeded that of year one. Total standing crop biomasses reached 10 t/ha, after the second growing season. Considering that the growing season is only about 80-90 days, this standing crop compares favourably with agricultural crops (Black 1982).

Vegetation layers in fresh tailings provide a source of carbon and nutrients for heterotrophic bacteria. Heterotrophic bacteria, including *Pseudomonas*, *Escherichia* and *Bacillus* spp. commonly inhabit soils (Paul and Clark 1989). Growth rates of these bacteria under optimum (laboratory) conditions range from *Pseudomonas putida* (0.75 hr), *Escherichia coli* (0.35 h), and *Bacillus subtilis* (0.43 h; Stanier et al. 1970). Growth rates of *Thiobacillus*, however, are considerably slower (0.12 h; Barron and Lueking 1990). Thus, under the same ideal conditions, heterotrophic bacteria will probably outgrow *Thiobacillus*.

Assuming that respiration rates are proportional to growth rates, heterotrophs will very effectively outcompete the thiobacilli for oxygen. Further, if oxygen transport through the tailings is a limiting factor for the tailings oxidation rate, then the presence of heterotrophs in large numbers will significantly reduce the tailings oxidation rate.

The presence of heterotophs in the root zone of the grass from the field plot after the 2nd year has been confirmed. Relatively few bacteria were found in the milling circuit, suggesting that bacterial growth in tailings areas was the result of providing nutrients. Vegetated areas had more heterotrophs than non vegetated controls. Thiobacilli were found in almost all samples, both vegetated and non-vegetated.

In conclusion, these experiments have demonstrated that it is possible to vegetate fresh tailings. Heterotrophic bacteria are numerous in the root zone. Further work is now required to establish the quantities of nutrients supplied to the heterotrophs in the root zone and to produce a moisture containing and acid neutralizing layer for acid water generated in the deeper parts of the tailings.

Acknowledgements

The support of this work by BP Resources is greatly appreciated.

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THE USE OF WASTE MATERIALS AS POTENTIAL COVERS ON MILL TAILINGS AT TIMMINS, ONTARIO

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ABSTRACT

In 1973, Falconbridge Ltd. (Kidd Creek Division) of Timmins Ontario implemented the Thickened Tailings Disposal method, which involves the deposition of tailings at 60-65% solids, resulting in a relatively stable and erosion-resistant tailings mass. The TTD method attempts to maintain the tailings at moisture saturation, thereby limiting oxidation and thus metal and acid drainage from the tailings. In conjunction with this disposal method, the company is considering the use of de-pyritized and gold tailings, as well as other waste materials such as sewage incinerator ash and granulated slag, as a cover to aid in the revegetation of the site. Growth experiments have shown that none of the materials has a significant effect on germination. De-pyritized tailings appear to provide a better growth medium than pyritic tailings, especially with respect to root growth. Gold tailings support the best root growth, while sewage incinerator ash gives the best leaf growth. In a column leach test, the amount of iron leached from the column was elevated under a cover of gold tailings, sewage incinerator ash or slag, while the amount of copper leached out was increased under a depyritized tailings cover. Apart from these exceptions, amounts of metals leached remained the same or were reduced under each of the covers.

Introduction

The Kidd Creek metallurgical site is situated twenty-six kilometres east of Timmins, Ontario. It is mainly a copper-zinc milling complex, although indium is a recently added product. Because of the sulphide nature of the ores and the presence of pyrite, the tailings are potentially acid-generating.

In 1973, Falconbridge Ltd. (Kidd Creek Division) adopted the Thickened Tailings Disposal (TTD) System for its tailings pond, on the recommendation of E.I. Robinsky Associates Ltd.. The TTD system involves the deposition of tailings at 60-65% solids, producing a cone-shaped tailings deposit. This is a much more stable and erosion-resistant tailings mass than the traditional version, because the homogeneous nature of the deposit and the sloped surface allow rapid surface runoff and drainage (Robinsky, 1979; Salvas, 1989). The TTD method attempts to maintain the tailings at moisture saturation, limiting oxidation, metal release and acid drainage.

The chemical oxidation of sulphides near the surface of pyritic tailings normally leads to acidification, and the acid water percolating through the waste is able to dissolve and transport a variety of materials in the leachate water (Doepker, 1988). Not only do a portion of these dissolved constituents remain on-site, where they become part of the ion balance of the soil water and possibly affect plant establishment and growth (Gentry *et al*,, 1992), but they also exert an effect on surrounding areas, through addition to groundwater and surface runoff. An advantage of the TTD approach is that it allows the progressive reclamation of the tailings during the active life of the operation, so that reclamation activities can ideally proceed on relatively fresh, unoxidized (neutral) tailings. Under these conditions, the application of a suitable cover may prevent or at least delay the oxidation of the tailings and subsequent enhanced metal release, so long as the pH remains high enough to prevent oxidation by *Thiobacillus ferrooxidans*, which can use ferric iron as an oxidizing agent under near-anoxic conditions below pH 4. According to Hammack and Watzlaf (1990), once bacterially-mediated pyrite oxidation is established, the oxygen partial pressure would have to be maintained below 1% to realize any reduction in oxidation rate. Cover materials that are capable of maintaining these low oxygen values, other than water, are not currently available or economically feasible. However, Hammack and Watzlaf also report that if bacteria are inhibited, any reduction in oxygen partial

pressure from atmospheric will result in a proportional decrease in the pyrite oxidation rate.

When covering materials are placed on potentially acid-generating and metalliferous tailings, they perform a dual purpose. On one hand they assist in achieving the aesthetic and ecological benefits of revegetation by acting as a substrate for plant growth. At the same time they limit the accessibility of oxygen to the pyritic material, and control the infiltration and runoff of H_2O, thus limiting the oxidative weathering of pyrite and retarding or eliminating the production of acid (Hoving and Hood, 1984). The initial goal of this project was to determine whether the addition of a layer of depyritized tailings as a relatively inert cover at the final stage of spigotting would be an economically feasible and worthwhile undertaking. Since the physical nature of depyritized tailings is essentially the same as that of pyritic tailings, the depyritized layer could be spigotted as thickened tailings in similar fashion as the pyritic tailings. Winterhalder & Tisch (1991) found that, although optimal germination, establishment and growth of grass seedlings occurred when the seeds were buried no more than 0.25 cm deep in tailings, germination could occur at a considerably greater depth, and they concluded that the incorporation of seeds into the top centimetre of tailings slurry would be a feasible method of vegetation establishment. Kalin[1] (personal communication) has indicated that the incorporation of seeds into a tailings slurry is not feasible on an operational level because the seeds tend to float to the surface, but the present authors feel that this problem could be circumvented by the use of coated seeds.

It later became evident that the depyritization of the final run of tailings might not be feasible, and attention was turned to other inexpensive but effective covers. Winterhalder (1992) has demonstrated, on a field experiment level, the effectiveness of gravel and/or loam covers on the oxidized sulphide tailings of the Kam-Kotia site, also in Timmins. However, the Kidd Creek tailings pond comprises an area of approximately 1200 hectares, and requires the treatment of 50,000 cubic metres/day of waste water. This extremely large area makes it unfeasible to use conventional and expensive cover materials such as gravel and loam. Thus, attention was turned to other readily available, inexpensive, and potentially non-phytotoxic, non-polluting waste products such as gold tailings, sewage incinerator ash and granulated slag as cover materials. Making use of waste products in the revegetation of mine tailings is not only very economical, but it also eliminates the need for storage of these materials on a site of their own. The problem, however, is that these waste materials often themselves contain potentially toxic substances which may inhibit plant growth or may leach into the surrounding environment, and thus may only serve to worsen the problem.

The objectives of the present study were:

1) to determine the influence that each cover exerts on the leaching of heavy metals through a column, and

2) to determine the potential of the cover materials to support vegetation.

The material presented in the leaching column portion of this study is based only on data collected thus far, and does not represent a completed experiment.

Materials

Pyritic and depyritized tailings and granulated slag were obtained from Kidd Creek mines in Timmins Ontario. Gold flotation tailings were obtained from Royal Oak mines, an adjacent gold mine. Sewage incinerator ash was obtained from Toronto, through Kidd Creek.

The pyritic and depyritized tailings are extremely fine, with 91.7% and 87.4%, respectively, passing through a 200

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[1]Margarete Kalin, Boojum Research Ltd., 468 Queen Street East - Suite 400, Toronto, Ontario M5A 1T7.

mesh (75μm) sieve. Pyritic tailings showed a net acid-producing potential of 139 kg/tonne, while the depyritized tailings only showed a slight acid producing potential of 3 kg/tonne. The gold tailings were more coarse, with only 27.4% passing through a 75 μm sieve, but showed a net acid consuming potential of 15 kg/tonne.

Among the limited analytical data available on the materials were those for Ontario Ministry of Environment Regulation 309 leachate extractions of pyritic and depyritized tailings. In these materials, only cadmium was at a "registerable" level, but the element was not present in high enough levels to be considered hazardous. Unfortunately, accurate figures for total cadmium content of the materials are not available at this time, but it is known that neither in pyritic nor in depyritized taiilngs does the cadmium content exceed 1,000 ppm.

The neutralizing material used was agricultural grade dolomitic limestone, and the fertilizer was a 6-24-24 agricultural grade product.

The "Sudbury seed mixture" variant used had the following composition by weight:

Agrostis gigantea	Redtop	10%
Festuca arundinacea	Tall Fescue	30%
Phleum pratense	Timothy	20%
Poa compressa	Canada Bluegrass	10%
Poa pratense	Kentucky Bluegrass	20%
Trifolium hybridum	Alsike Clover	10%

Methods

All materials were air-dried and thoroughly mixed prior to storage. The pyritic, depyritized and gold tailings were reduced to their original size range after drying by grinding lightly, but they were not sieved. The incinerator ash and granulated slag were passed through a 2 mm sieve in order to obtain a more homogeneous sample.

Total Analysis of Materials

All materials were analyzed for total element content by x-ray fluorescence.

Pot Bioassay

This experiment was designed to determine the effect of dolomitic limestone and fertilizer, singly and in combination, on the productivity of a grass mixture grown on pyritic tailings, depyritized tailings and a 50-50 mix of the two.

The experiment was based on a randomized block design, with 5 blocks (replicates), i.e.

3 growth materials x 4 treatments x 5 replicates = 60 pots.

Treatments were as follows:

Treatment 1 - Control
Treatment 2 - 1 g limestone per pot
Treatment 3 - 0.25 g fertilizer per pot
Treatment 4 - 1 g limestone + 0.25 g fertilizer per pot

One hundred grams of tailings, with the addition of the appropriate amendment, were thoroughly mixed in a small plastic bag before being placed in a 9 cm diameter square pot. A Number 3 Whatman filter paper had been placed in the bottom of each pot in order to retain the tailings.

After thoroughly wetting each pot, 0.2 grams of Sudbury seed mixture were sown at a depth of approximately 0.25 cm.

The experiment was set up in a greenhouse, and watered regularly with demineralized water for approximately 3 months, at which time the resulting vegetation was harvested. Harvesting consisted of clipping the above-ground portions at the tailings surface, and placing them in small paper envelopes. The pH of the tailings surface was determined, and the roots were carefully washed out of the tailings and also placed in small paper envelopes.

All samples were then oven-dried at 70-80°C, and the dry weight determined.

Petri Dish Bioassay

This experiment tested the effect of each of the cover materials, with and without the addition of dolomitic limestone, on germination and early root and leaf growth of a grass, using the technique developed by Archambault (1991). It was at this time that the project was expanded to include gold tailings, incinerator ash and granulated slag as alternate covers or revegetation aids.

All treatments were replicated five times in a randomized block design, i.e.:

5 materials x 2 treatments x 5 replicates = 50 plates.

Glass fibre filter paper was placed in the bottom of a small plastic Petri dish, in which ten small holes had been drilled. Twenty grams of pyritic tailings, depyritized tailings, incinerator ash, granulated slag or gold tailings respectively, with or without the addition of 0.2 grams of dolomitic limestone, were then placed on the filter paper and covered with another filter paper. Fifty seeds of *Agrostis gigantea* (Redtop) were placed on the top filter paper.

The lid was replaced on the plastic Petri dish, which was then placed in a larger glass Petri dish, to which water was added. The water moved up through the holes in the bottom of the plastic Petri dish, through the 'soil', moistening the filter paper and seeds (Fig. 1).

The plates were kept mainly under darkened conditions until germination occurred, then were subjected to normal daylight conditions for a period of 8 days. Percent germination was determined, and root and shoot growth were measured to the nearest millimetre.

Leaching Column Construction

Leach columns (Figure 2) were constructed of 47 cm lengths of 10 cm (I.D.) PVC pipe. A 10 cm sewer cap was glued and siliconed to one end of each column. Prior to gluing, each cap had been heated and moulded into a more funnel-like shape to facilitate drainage. A drain was created by drilling a hole into the cap, and inserting half of a plastic tubing connector, which was then glued into place. The tubing connector had been cut and sanded so as to be flush with the inside bottom of the cap. The outside of the drain was also siliconed to provide further support and to prevent leakage.

The columns were placed on a wooden table and seated on a styrofoam pad. Holes had been drilled through the table to facilitate the positioning of the drain, which was connected to a 500 ml plastic sample bottle located under the table *via* a piece of Tygon tubing. This was achieved by drilling a hole through the lid of the sample bottle and inserting the other half of the plastic tubing connector. When the columns had fully drained, the sample bottle was simply unscrewed from the lid and then sealed with a fresh lid. Between leaching cycles, movement of air through the bottom of the column was prevented by a plastic clamp that had been installed on the Tygon tubing.

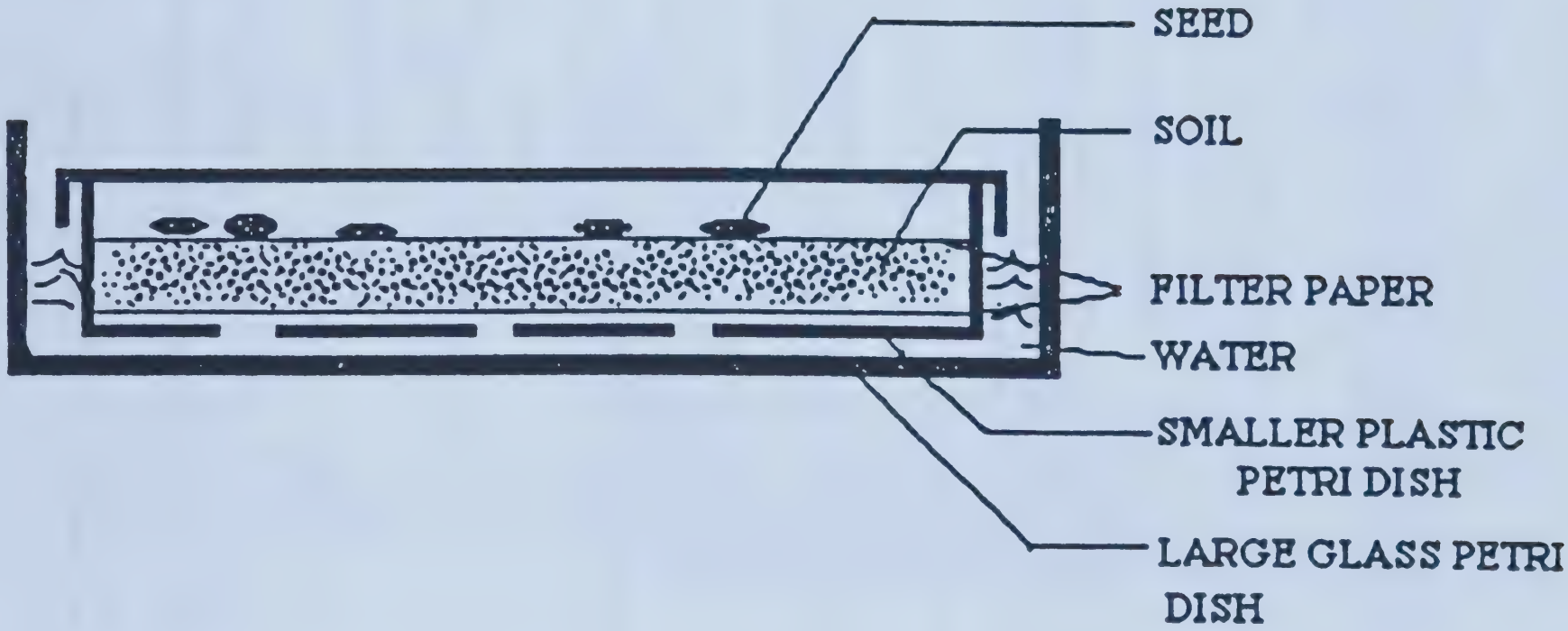


Fig. 1: Petri Dish Design

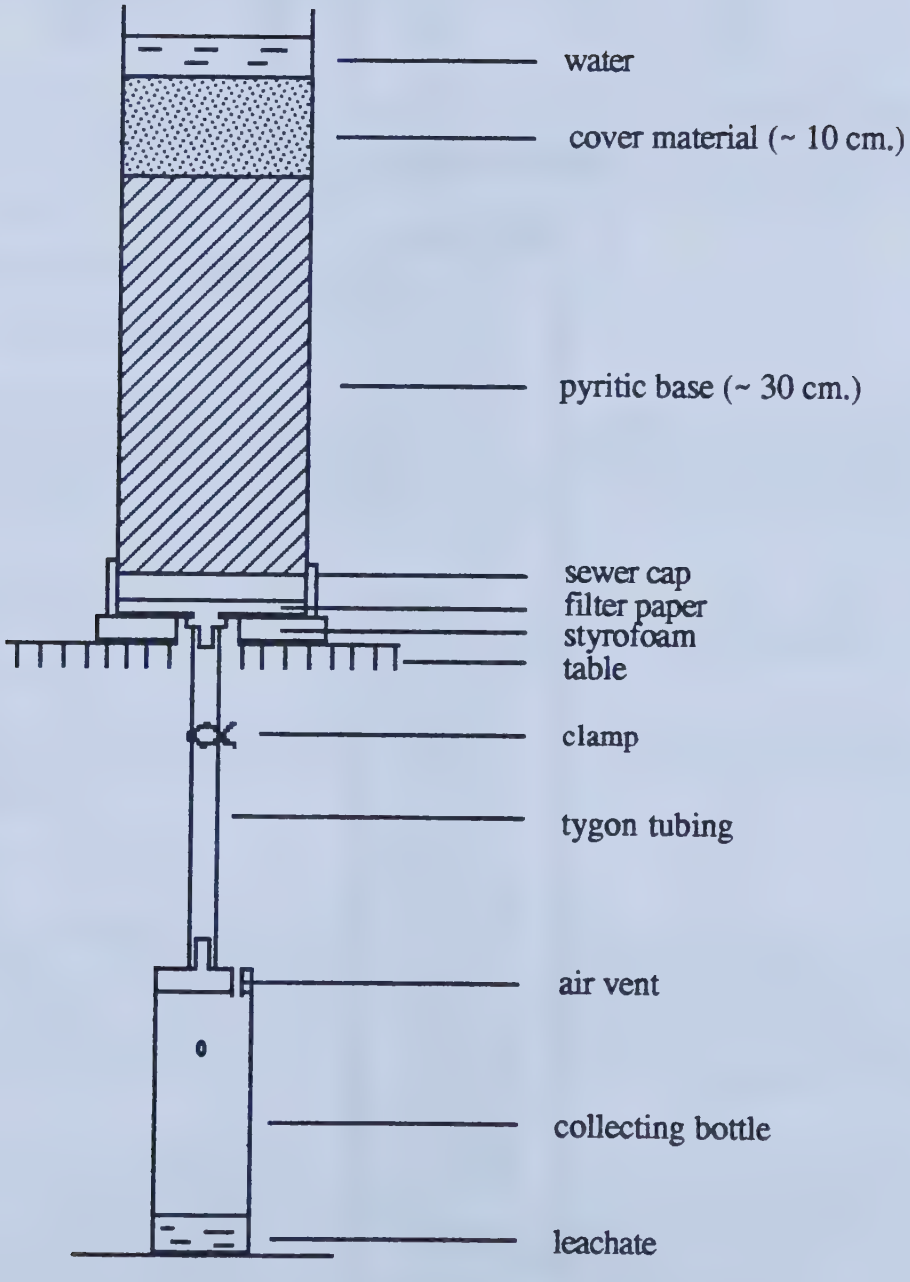


Fig. 2: Leaching Column Design

Leaching Column Experiment

All columns were first loaded with a pyritic tailings base, consisting of 4 kg of dried tails added in 1 kg increments as a slurry (approx. 2.7:1 tails:water by volume ratio), representing a depth of approximately 30 cm. An attempt was made to dislodge air bubbles and promote uniform packing by tapping the columns with a brass bar after each 1 kg addition of tailings.

The experiment was designed to investigate the effect of the use of five covers (depyritized tailings, gold tailings, incinerator ash, granulated slag and, as a control, pyritic tailings) and two treatments (limed and unlimed) on effluent chemistry. The experiment had the following design:

5 covers x 2 treatments x 5 replicates = 50 columns

Cover materials were added by weight so as to obtain a depth of approximately 10 cm. Thus, an additional 1300 g of pyritic tailings were added to the control, while 1200 g of each of depyritized and gold tailings, 750 g of incinerator ash, and 1600 g of granulated slag were utilized in their respective columns. The pyritic and depyritized covers were added as a slurry, while the gold tails, ash and slag were added in dry form.

The limed treatment was achieved by mixing 12 g of dolomitic limestone into each cover material in a 1000 ml beaker before adding it to the pyritic base.

The columns were thoroughly soaked, and tapped again to try to remove air bubbles. The clamps were opened and the columns allowed to fully drain. Leaching began with the addition of 200 ml of distilled-deionized water. The quantity of leachate and the time were recorded periodically, so as to obtain an estimate of the infiltration rate.

When a constant leachate volume was obtained, the sample bottles were taken to the laboratory, where the pH and conductivity were determined. The samples were then acidified with nitric acid to a pH of approximately 2, and placed in acid-washed vials for elemental analysis by ICP. All samples were stored in a refrigerator until analyzed.

The columns were leached weekly for the next 4 weeks, after which time it was deemed that the columns were not drying sufficiently between watering, and the leaching cycle was extended to once every two weeks.

Results and Discussion

Total Analysis of Materials

The results of the analysis are shown in Table 1.

Table 1: Total Content of Select Elements.

Cover Type	Al (%)	P (%)	Fe (%)	S (ppm)	Cr (ppm)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Pb (ppm)
Ash	3.34	7.98	14.15	1849	1075.9	194.4	3551.8	6316.7	495.1
Gold	7.18	0.07	4.17	968	151.3	36.1	5.0	69.7	9.3
Slag	0.84	0.06	16.64	3684	245.6	43.5	6961.1	53364	366.5
Depyr.	5.16	0.01	8.09	4463	65.3	30.3	449.6	1711.1	100.7
Pyritic	4.22	0.02	9.26	21880	61.3	42.0	1502.7	5957.2	537.2

It is notable that at least one potentially phytotoxic metal is present at a concentration of greater than 1000 ppm in each of these materials (e.g. chromium in incinerator ash, slag and both forms of tailings). However, these total values give little indication of the amount of metal that is soluble under normal growth conditions, and it is hoped that leaching and growth trials will give some indication of their true phytotoxic (and zootoxic) potential. From the point of view of plant nutrition, the high phosphorus content of the ash is beneficial, but as in the case of the metals, its plant-availability is in question.

Pot Bioassay

The results of the pot bioassay, which was designed to determine the effect of pyrite on the relative growth of vegetation over approximately one field season (appr. 3 months), are summarized in Figures 3, 4 & 5. Although there was no significant difference in % germination between pyritic and depyritized tailings, there was a very pronounced increase in root and shoot weight in depyritized tailings (Figure 3). Surprisingly, this difference in growth does not appear to be due to the oxidation and subsequent acidification of the pyrite in the pyritic tailings, as there was no significant difference in surface pH between pyritic, depyritized and the 50/50 mix (Figure 4). The improved performance in the depyritized tailings was possibly due to a mild inhibitory effect on plant growth by sulphide ions in the pyritic tailings, or to decreased heavy metal content in the depyritized tailings as a result of the depyritization process, as indicated in Table 1. While the main goal of depyritization is the removal of FeS2 (pyrite), associated sulphides such as CuS, ZnS, and PbS may also be removed.

The results of this experiment also showed that the addition of lime did not significantly affect root or shoot weight (Figure 5). This might be expected, since the initial Ph of both materials was already neutral to alkaline, but the calcium and/or magnesium in limestone can interact with other metals and modify their toxicity. While limestone alone had little effect on growth in either type of tailings, it was beneficial when combined with fertilizer (Figure 5).

Petri Dish Bioassay

The results of the Petri dish experiment, which was designed to determine relative growth during the period immediately following germination (app. 7 days), i.e. during seedling establishment, are shown in Figure 6. Depyritized tailings, gold tailings, and incinerator ash all produced significantly better root growth, while granulated slag produced significantly lower root growth than pyritic tailings. Incinerator ash produced significantly better shoot growth, probably due to a high phosphorus content, while slag produced significantly lower shoot growth. It should be noted that the variation in shoot growth is much lower than that found in root growth. Roots, being in direct contact with the growth medium, usually react in a more sensitive fashion than shoots during early seedling growth, and hence are the most commonly used indicators of toxicity, as pioneered by Wilkins (1957).

Although these experiments have shown that growth directly on the pyritic tailings is possible under greenhouse conditions, field trials have indicated that such an approach is unlikely to be successful under field conditions, even with the use of ameliorants such as lime and fertilizer. This failure is likely to be due to physical problems such as drought and abrasion during seedling establishment, combined with a strong salinity effect. Field trials have shown this to be the case with gold tailings also; although they showed the best growth potential under greenhouse conditions, a vegetative cover failed to establish in the field.

Leaching Column Experiment

The column leach study has shown several trends in the release of metals from the system, as indicated in Figures 7-10. It is important to look not only at the concentration of metals in the leachates, but also at the

total amount of metal leached from each column under a specific leaching regime. Since the volume of leachate obtained in a single leaching event depends on the pore volume of the materials in the column, treatments producing the same **concentration** of metals in the leachate may leach quite different **amounts** of metal due to difference in the **volumes** of leachate obtained. Thus, the release of metals is not only dependent on chemical alterations within the material, but also on the physical characteristic of the material. The effluent from tailings covered with incinerator ash has a similar concentration of cadmium to that from tailings covered by other materials (Figure 7a), but a smaller amount of cadmium has been leached out due to a smaller volume of effluent (Figure 7b).

In general, it was expected that there would be a rather rapid release of metals over the first few leaching cycles, followed by a steady decline until a constant level was reached, such as is seen in the case of cadmium (Figure 7). These results are similar to those of previous studies, and are thought to be due to the flushing of easily-leached metal forms from the column (Doepker and O'Connor, 1990a & b).

Other metals such as zinc (Figure 8) exhibit a similar pattern of release, although the rapid decrease does not occur until after several leachings. This is likely due to the presence of a sink of these metals, which requires several flushings before all of the easily leached material is released, or simply that it takes longer for these metals to move through the columns.

Once a constant concentration of ions is obtained with successive leachings, it is assumed that the easily-leachable ions have been removed, and that any ions that are still being leached are due to the weathering or decomposition of the tailings or cover (Gentry et al., 1992).

Treatment of the cover materials with lime had no significant effect on the quality of the leachate. Having and Hood (1984), in looking at different thicknesses of limestone and soil over pyritic material, found that lime had a very limited effect on improving the quality of the effluent. This was further demonstrated by Doepker (1991), who found that abatement treatments such as phosphate, lime and sodium lauryl sulfate were of only marginal value in improving leachate quality.

It was found that cumulative graphing of the amounts of metals leached, which represent potential metal "loadings" to the surrounding environment, best discerned the effects of the different cover materials on metal release. In general, the four cover materials studied resulted in the same or decreased amounts of metals leached out, with the exception of the increased iron from gold tailings, incinerator ash and slag (Figure 9a), and the increased copper from depyritized tailings (Figure 9b). In the case of iron, increased levels would be expected from ash and slag due to their high inherent content (Table 1). Gold tailings, on the other hand, contain half the iron of pyritic tailings, yet showed much higher levels in the leachate (Table 1). This is possible due to a more soluble form of iron in gold tailings. It is thought that these increased iron levels over time for gold tailings, ash and slag are the result of a rather slow rate of movement of iron through the pyritic tailings, and that these values will continually decline over the next few leach cycles.

Depyritized tailings have shown consistently greater leaching of copper over time than pyritic tailings (Figure 9b). This result was not expected, as is not yet understood. Total copper in the depyritized tailings is much lower than in the pyritic tailings (Table 1), yet more is leached from the former. Why the depyritization process should affect copper, but not other metals such as lead and zinc, is not known.

Gold tailings, ash and slag covers all gave decreased total levels of cadmium in the leachate (Figure 10). This appears to be due to a lower volume of leachate produced, as illustrated in Figure 7, rather than the chemical influence of the cover.

Sewage incinerator ash is formed by the combustion of sewage sludge, which results in the concentration of metals in the ash. Specifically, this ash contains comparatively high levels of Fe, Cr, Ni, and Cu (Table 1),

and would be expected to release these metals through leaching processes, especially in the absence of organic matter. The gold tailings, on the other hand, are thought to be relatively inert, even though they contain comparatively high levels of Al and Cr. Granulated slag is also considered to be inert, despite high levels of Fe, Cr, Cu and Zn (Table 1). In spite of these differences, all three of these covers behaved in the same fashion, resulting in elevated leachate metal levels for iron alone.

The lower net acid producing potential of depyritized tailings, the net acid consuming potential of the gold tailings and the high phosphorus content of the ash certainly make these materials worthy of further consideration as cover materials, as long as they continue to show no dramatic increase in leaching of potential toxins.

The physical characteristics of granulated slag do not make it suitable for use as a cover, although the potential does exist for its use as a capillary break between the pyritic tailings and a cover material.

Fig. 3a:

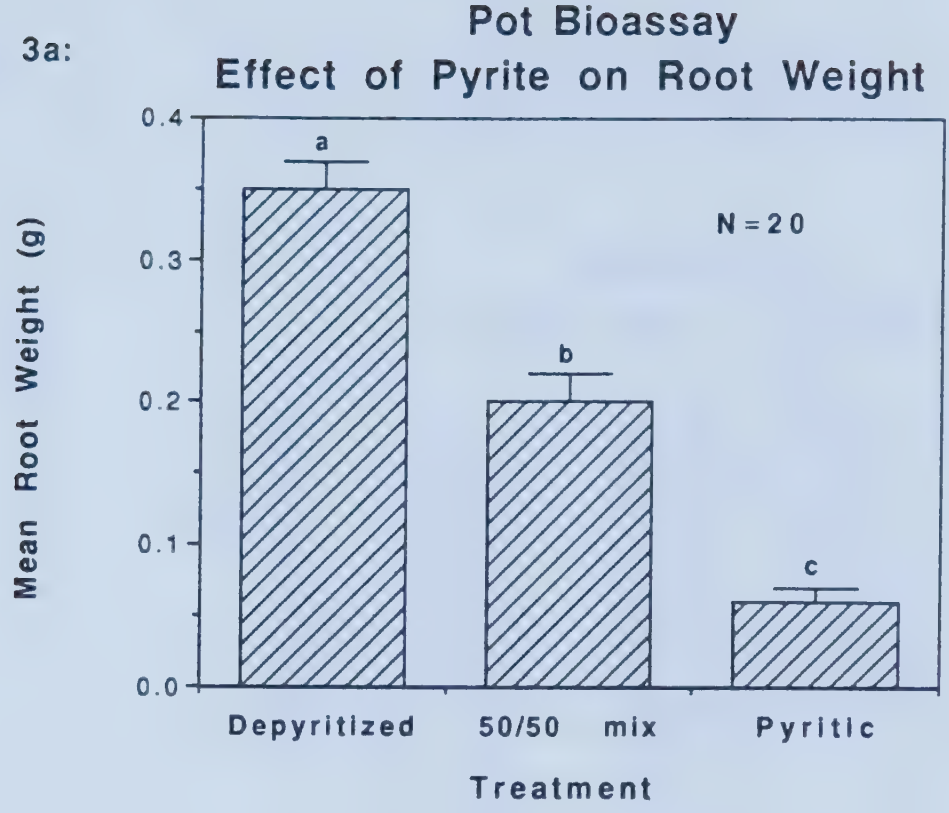
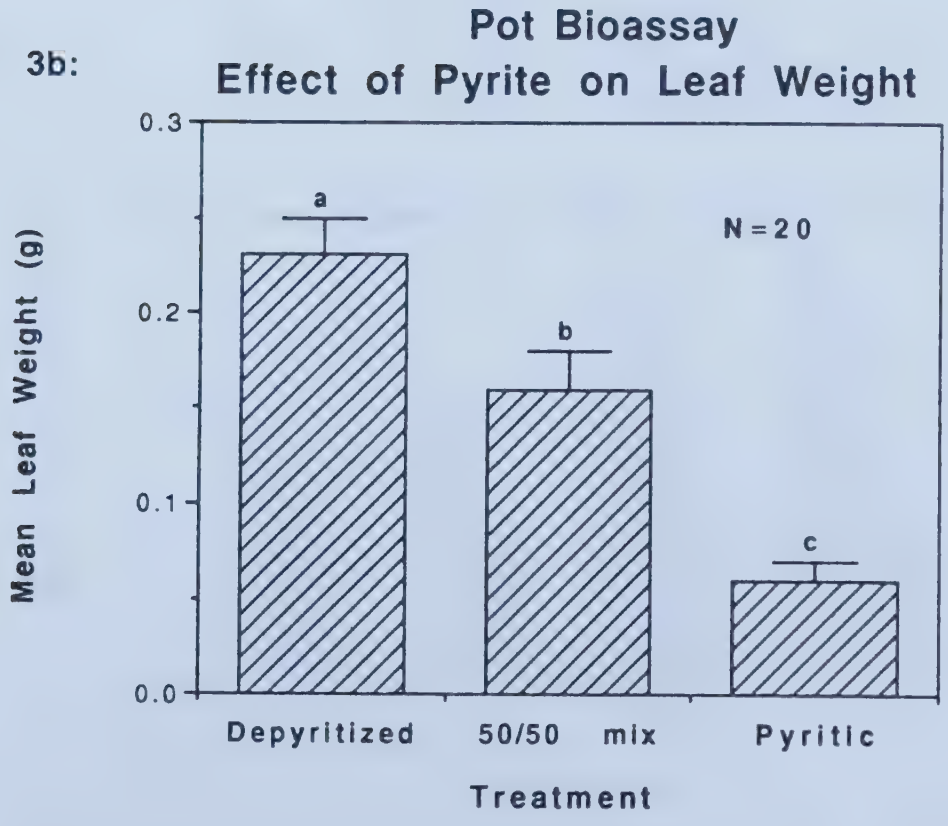
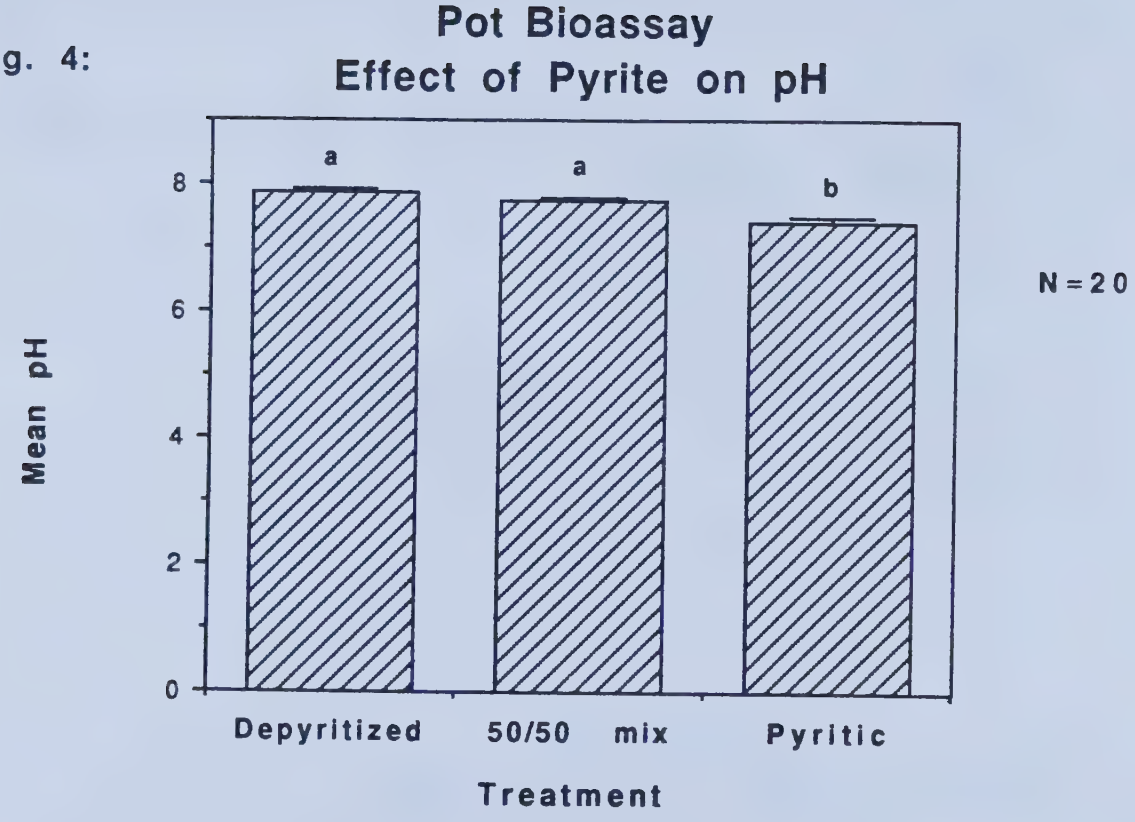


Fig. 3b:



Bars with the same superscript do not differ significantly at the 5% level.

Fig. 4:



Bars with the same superscript do not differ significantly at the 5% level.

Fig. 5a:

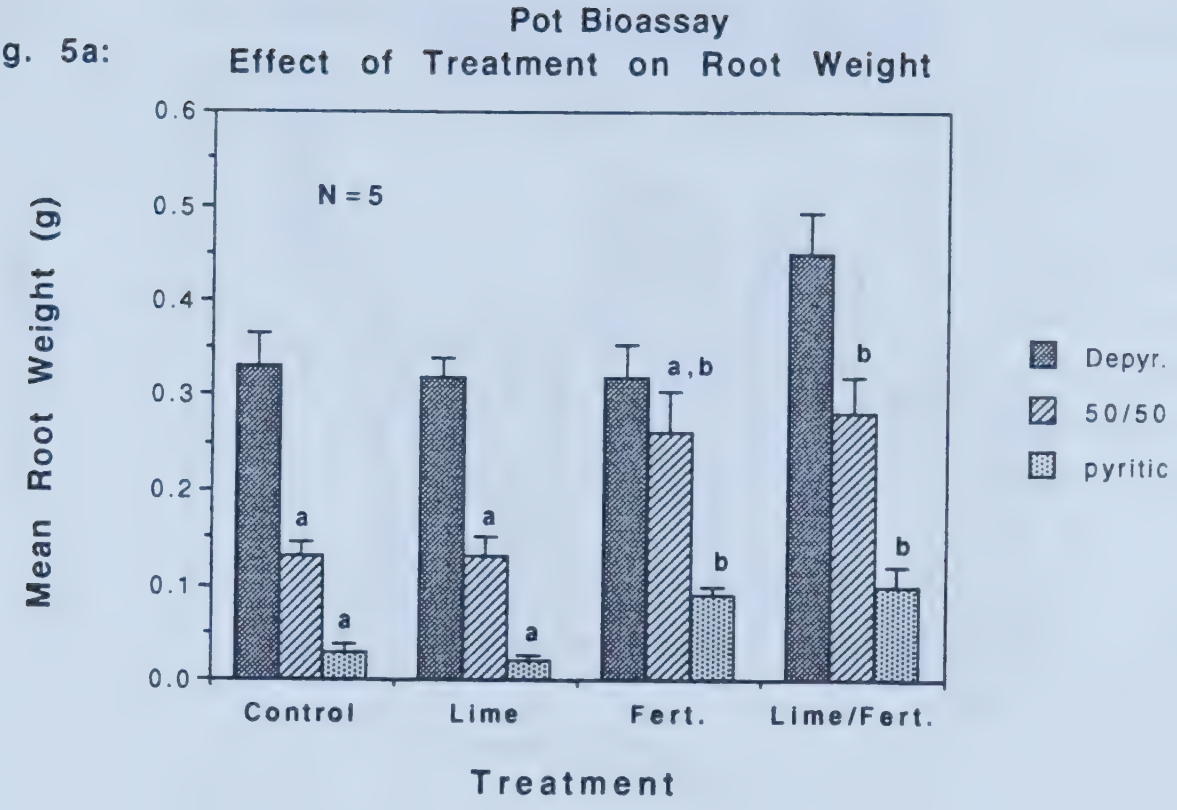
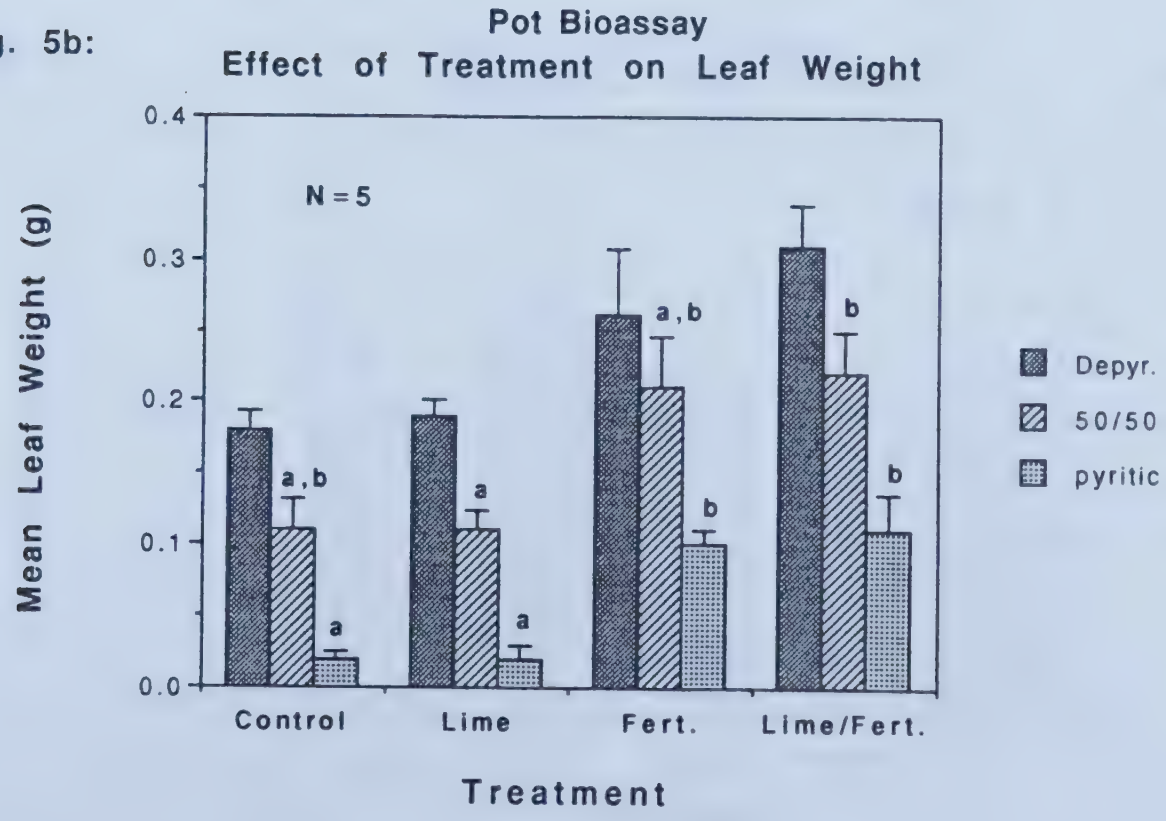


Fig. 5b:



Bars with the same superscript do not differ significantly at the 5% level.

Fig. 6a:

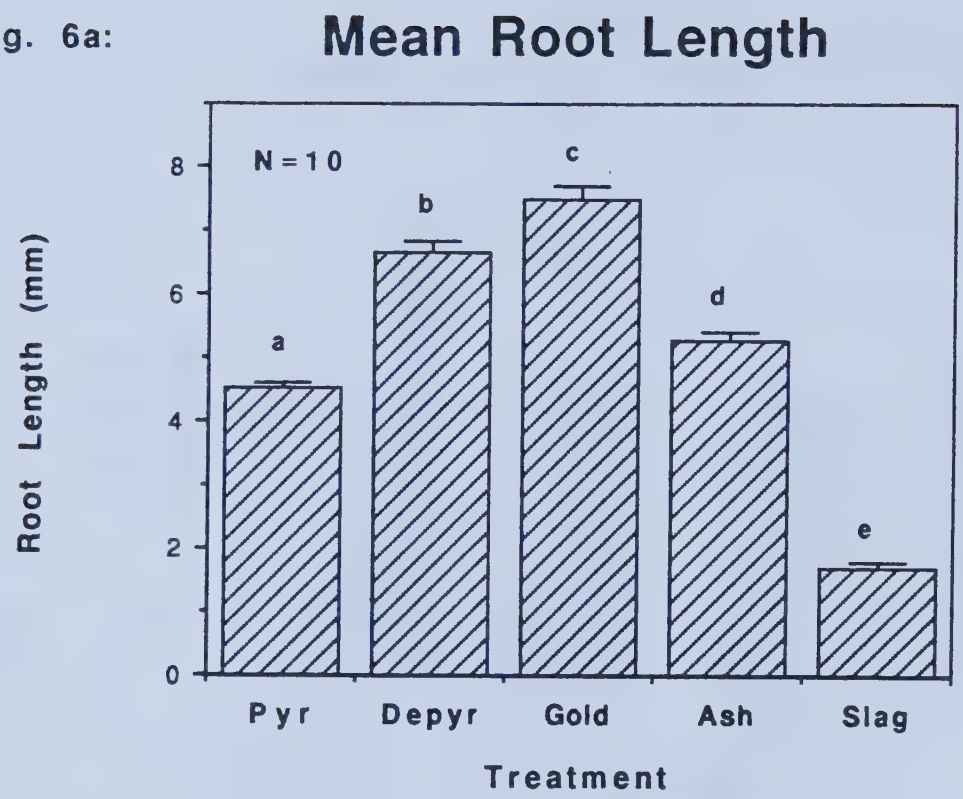
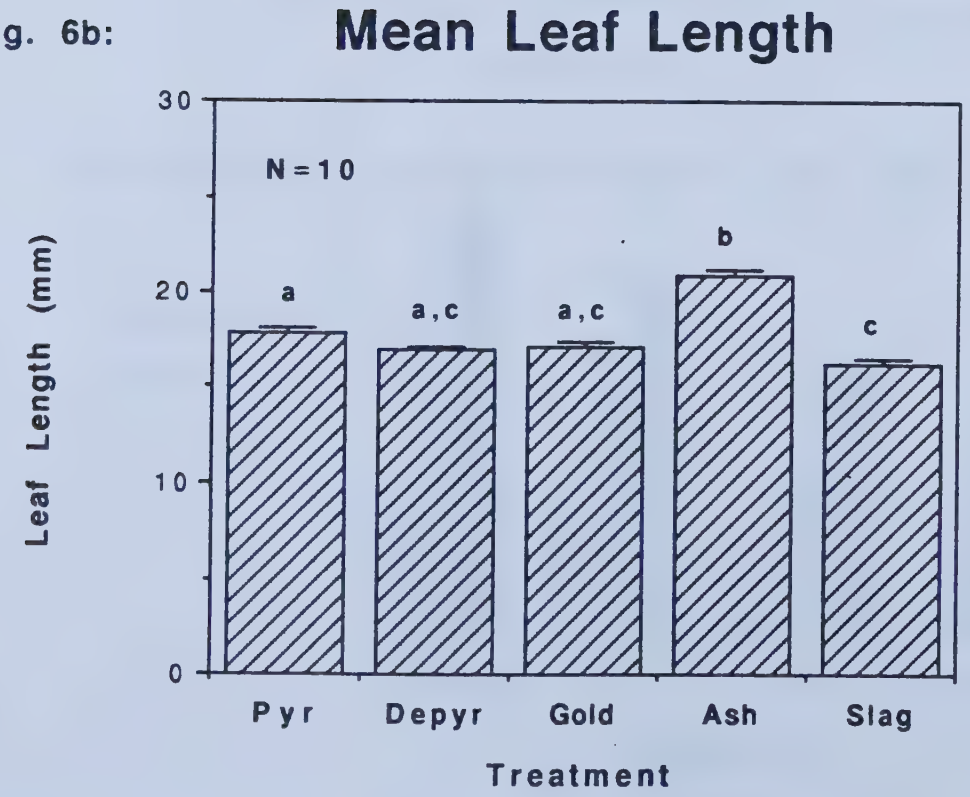


Fig. 6b:



Bars with the same superscript do not differ significantly at the 5% level.

Fig. 7a:

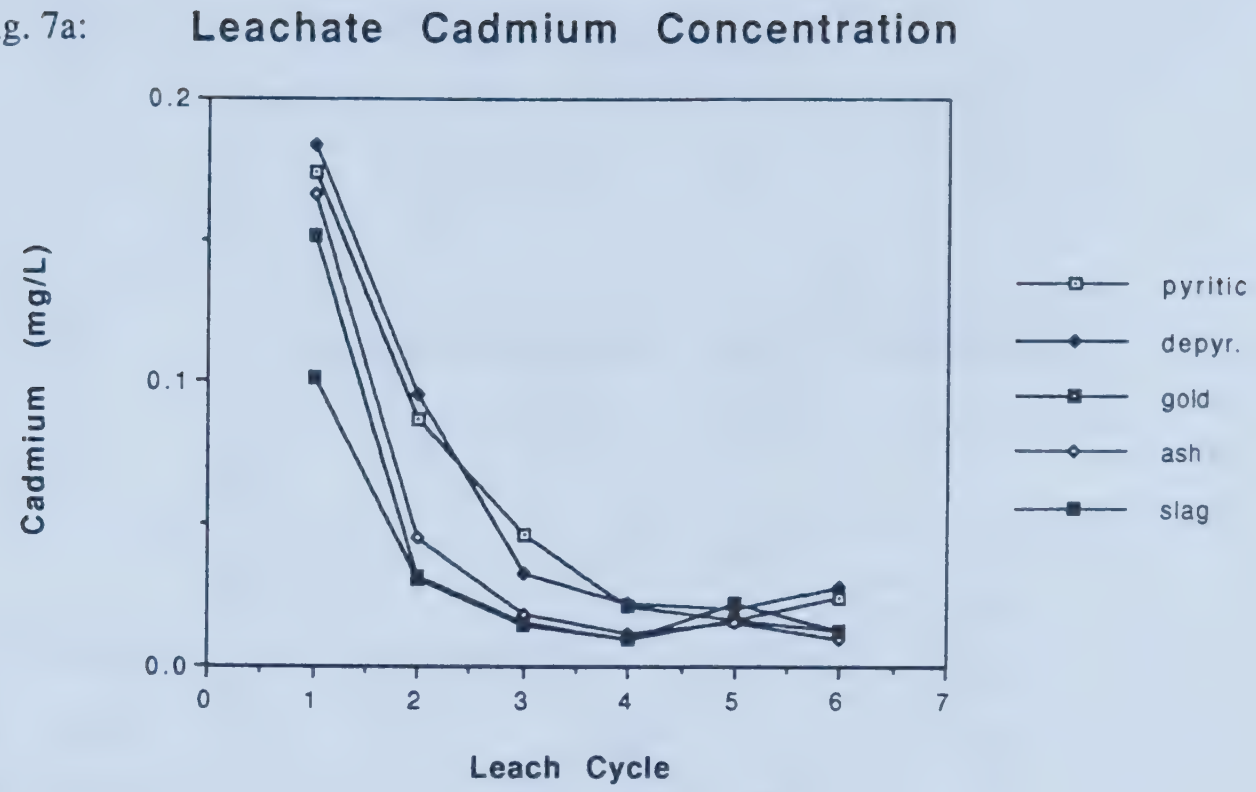

Leachate Cadmium Concentration
Cadmium (mg/L)
0.2
0.1
0.0
0
1
2
3
4
5
6
7
Leach Cycle
pyritic
depyr.
gold
ash
slag

Fig. 7b:

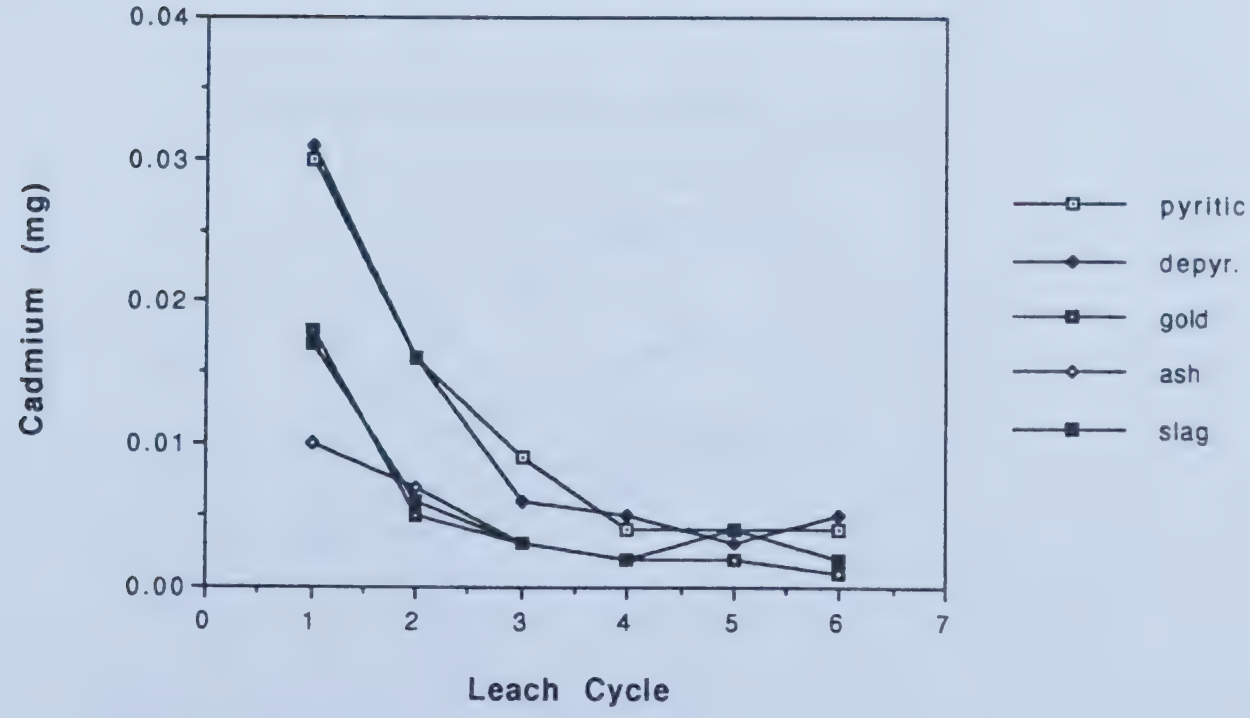

Total Leachate Cadmium
Cadmium (mg)
0.04
0.03
0.02
0.01
0.00
0
1
2
3
4
5
6
7
Leach Cycle
pyritic
depyr.
gold
ash
slag

Fig. 8:

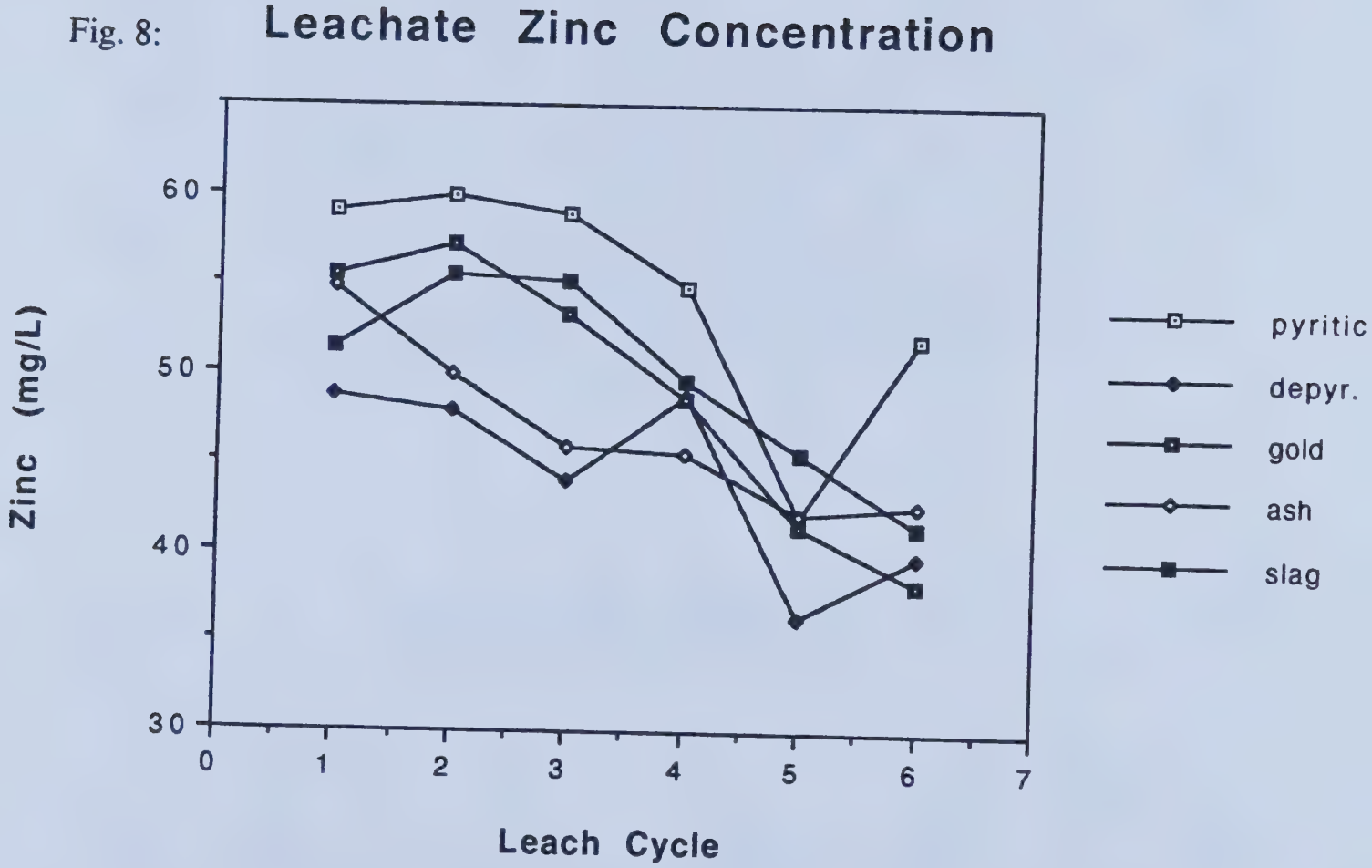

Leachate Zinc Concentration
Zinc (mg/L)
60
50
40
30
0
1
2
3
4
5
6
7
Leach Cycle
pyritic
depyr.
gold
ash
slag

Fig. 9a:

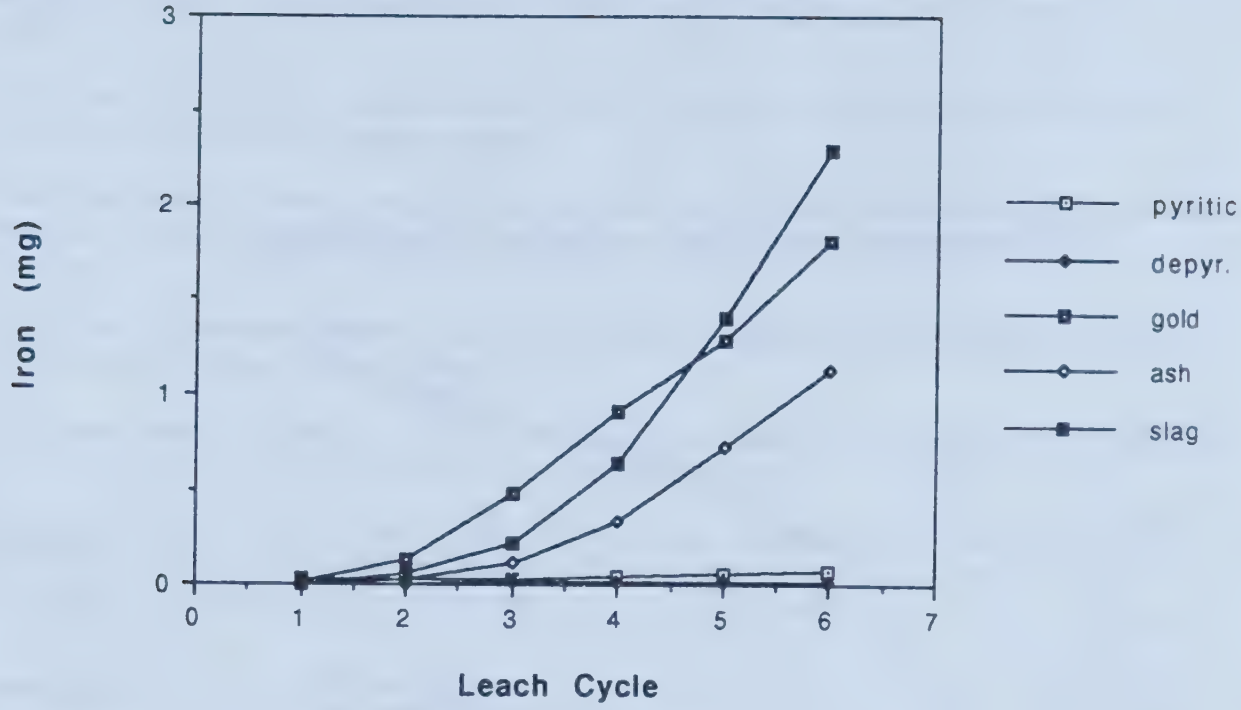

Cumulative Leachate Iron
Iron (mg)
Leach Cycle
0
1
2
3
4
5
6
7
pyritic
depyr.
gold
ash
slag

Fig. 9b:

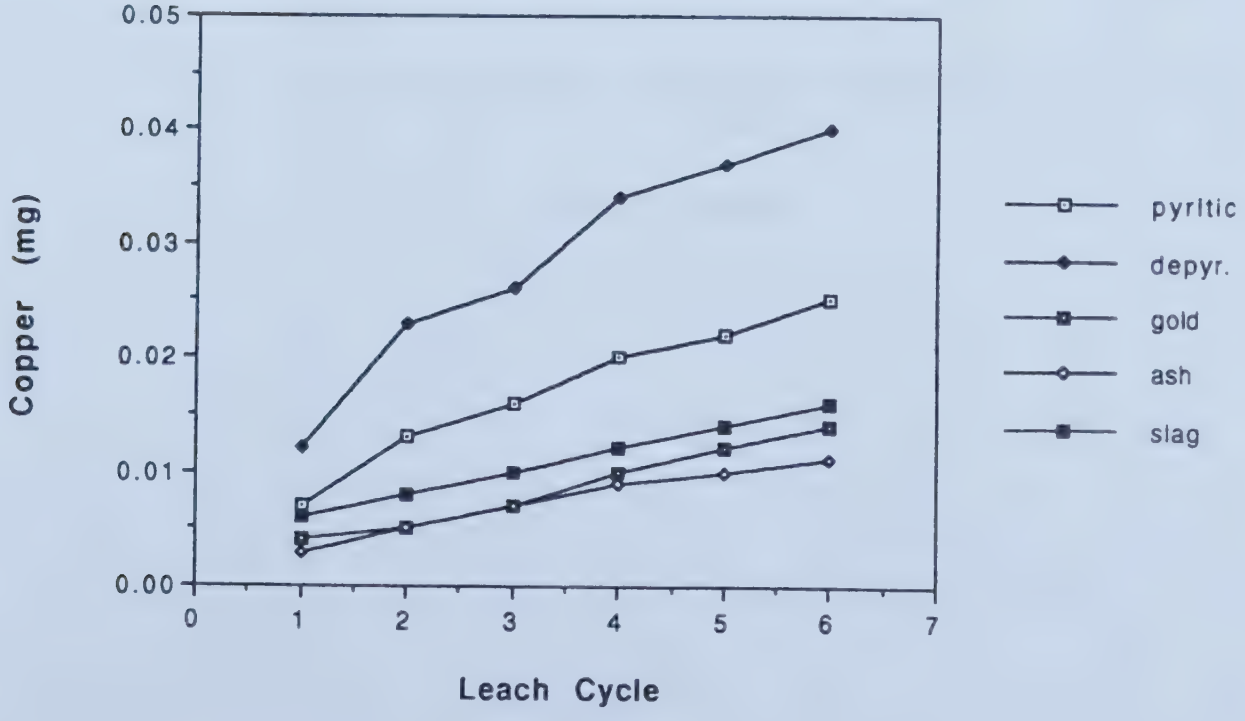
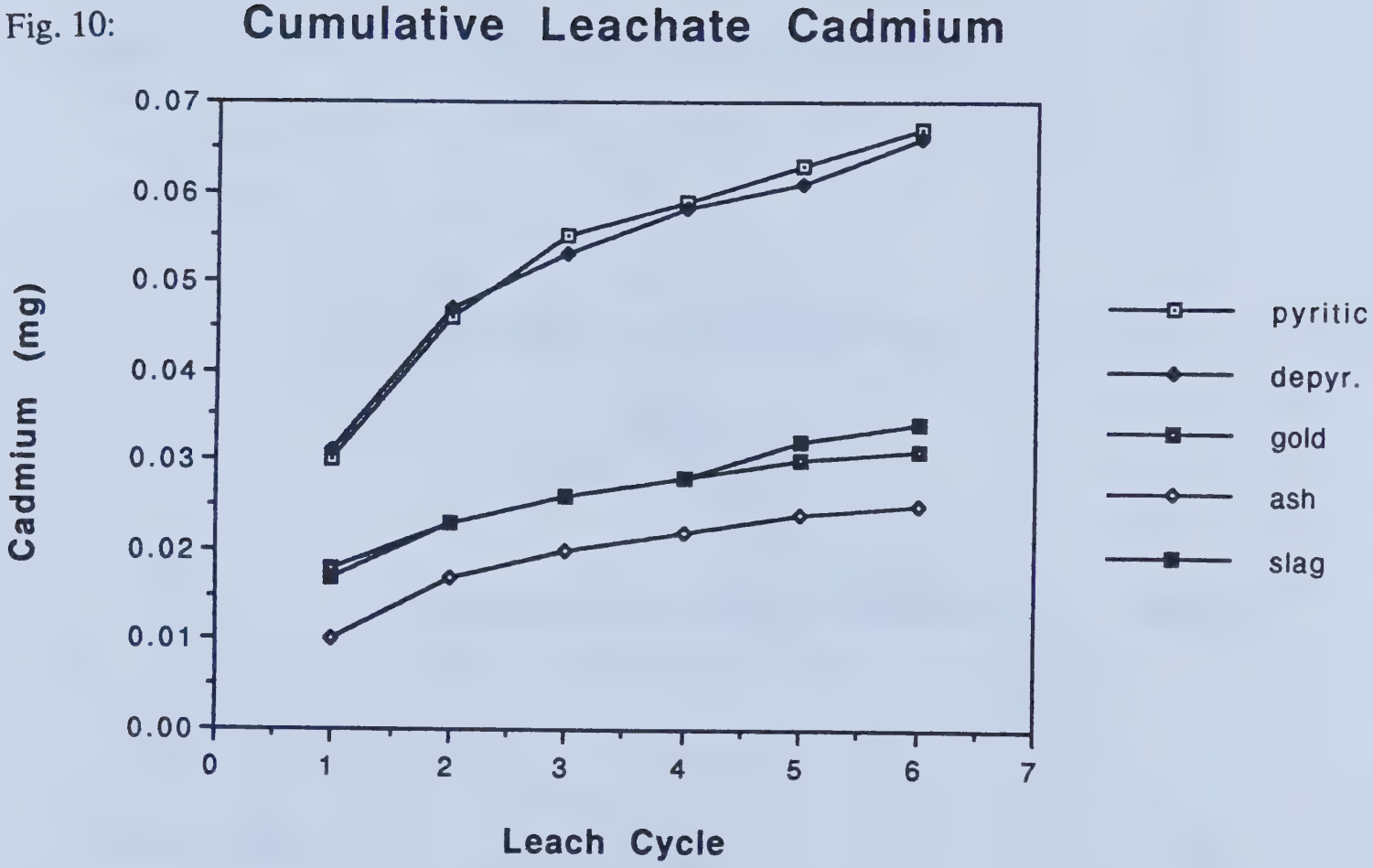

Cumulative Leachate Copper
Copper (mg)
Leach Cycle
0.00
0.01
0.02
0.03
0.04
0.05
0
1
2
3
4
5
6
7
pyritic
depyr.
gold
ash
slag

Fig. 10:


Cumulative Leachate Cadmium
Cadmium (mg)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
1
2
3
4
5
6
7
Leach Cycle
pyritic
depyr.
gold
ash
slag

Conclusions

1. Depyritized tailings provided a much better plant growth medium than similar tailings prior to depyritization, and exhibited the same or lower levels of metals in the leachate, with the exception of copper.

2. The leachate from depyritized tailings exhibited the same or lower levels of all metals, except copper, than that from similar tailings prior to depyritization.

3. Plant growth on pyritic tailings was signficantly improved by the addition of limestone and fertilizer, by the same was not true of depyritized tailings. The response to fertilizer was greater than the response to limestone.

4. When pyritic tailings were covered by a layer of gold tailings, incinerator ash or granulated slag, the levels of all metals were reduced, with the exception of iron.

5. Early plant growth on depyritized tailings, gold tailings, and incinerator ash was signficantly better than that on pyritic tailings, while that on granulated slag was significantly poorer.

In general, depyritized copper-zinc tailings, gold tailings and sewage incinerator ash provided a much better growth medium than pyritic tailings, without greatly contributing free heavy metals to the system. Studies are currently under way to attempt to confirm these observations under field conditions.

Acknowledgements

The study was funded by Falconbridge Ltd., and the assistance of Dennis Borden and Bernie Swarbrick is gratefully acknowledged. Metal analysis by ICP was carried out by the Kidd Creek laboratory, and Anna D'Agostino and Peter Clarke assisted in the preparation of samples for analysis. The Sudbury seed mix was provided by Jim Miller of the Regional Municipality of Sudbury.

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USING POPULATIONS OF SCIRPUS ATROCINCTUS, A SEDGE, FOR STABILIZING TAILINGS BEACHES AND TILL BERMS

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Toronto, Ontario

ABSTRACT

An important component of decommissioning mining operations is physical stabilization through revegetation of barren tailing areas and man-made peat berms. conventional revegetation, using agricultural seed mixtures, fertilizer and lime, are effective as long as the terrain allows access of machinery. Tailings beaches and peat berms are difficult to reclaim and stabilize permanently. The reclamation process is generally very costly, sometimes requiring repeated applications.

Indigenous plant species populating either the peat bog or the tailings areas have demonstrated their ability to colonize these substrates. This paper reports on utilizing local populations of Scirpus atrocinctus, a species of sedge, for the stabilization tests of peat berms and tailings beaches. This species was found growing on polymetallic, acidic tailings at Buchans, Newfoundland. See was collected from the vicinity of mine-disturbed lands and used for the stabilization tests.

Seed collection time, storage requirements, and the specific conditions required for seed germination and seedling establishment of Scirpus atrocinctus were examined in laboratory and field experiments. High light intensities and temperatures with adequate moisture were determined to be the critical factors for breaking seed dormancy. Supplementation of seedlings with an adequate nitrogen supply in moist conditions promoted good plant growth. A simple, cost-effective technique has been developed to rapidly vegetate and stabilize peat berms. Further experiments are required to obtain better results for tailings beaches.

Introduction

Decommissioning of mining operations typically requires physical stabilization of barren tailings areas, the plant site, and any areas disturbed during operations. Conventional revegetation measures apply agricultural seed mixtures, combined with fertilizer and lime, using machinery.

The use of conventional reclamation measures is, to a large part, restricted to areas accessible to machinery. Acid-generating tailings beaches and dams/berms are examples of this problem. Methods which facilitate establishment and growth of indigenous species in areas inaccessible by machinery are useful tools in rehabilitation.
Stabilization of acidic tailings beaches and peat berms was required at Buchans, Newfoundland. The Buchans mill and ore bodies are located within a 1.5 km radius of the town of Buchans, in west-central Newfoundland, Canada (Long. 56° 52', Lat. 48° 48'). The mines and mill operated between 1928 and 1984, producing copper, lead, and zinc concentrates, containing some gold and silver. A barite concentrate was produced for a short time.

A species of sedge, *Scirpus atrocinctus*, is the most abundant, and one of a very few species, which has colonized some areas of the tailings. This species is dominant in the wet sedge meadows and marshes, a common habitat in the west-central Newfoundland. *Scirpus atrocinctus*, commonly known as Wool grass, is a perennial sedge species with stout rootstocks, found in moist to swampy areas from Newfoundland to Ontario, as well in Saskatchewan and the southern United States (Britton and Brown, 1970).

This paper reports on the conditions for germination and establishment of seeds of Wool grass. Field trials are carried out, both on tailings and on peat berms, with the objective of devising a technique to establish sedge populations as self-maintaining vegetation covers.

MATERIALS AND METHODS

Laboratory Experiments

Seed Collection: Seed heads were cut from senescing plants in a wet sedge meadow near Buchans, Newfoundland on October 12, 1990 and air-dried at ambient temperatures in an unheated building for two weeks. Seed head samples were split into three sub-samples for storage in sealed plastic bags at room temperature (21°C), in a refrigerator (8°C) and in a freezer (-20°C). Samples were stored at the three temperatures for at least 70 days before laboratory experiments were performed.

The dried seeds were shaken from the inflorescences and the seed concentrate was gathered into pipettes using a vacuum pump. The seed concentrates were re-stored at room temperature, or in the fridge or freezer.

Seed Germination: Seeds stored at the three temperatures were scarified for different time periods. Scarification consisted of wetting seeds with 60 % sulphuric acid then thoroughly rinsing the seeds with distilled water. The seeds, suspended in distilled water with residual acid (pH 1.2 - 1.5), were then pipetted into plastic petri plates containing a layer of 0.8 % agar. The plates were capped, sealed with electrical tape, then placed 50 cm below four 1.22 m long "cool white" fluorescent lights (12 hr:12 hr, light : dark) and temperature controlled at $21 \pm 3°$ C.

The seeds were examined weekly for germination under a stereo microscope. Final counts of the total number, and the number of germinated seeds, were made after 16 days.

A second experiment was a repeat of the first, except only those seeds stored in the freezer were used, and a control (no scarification) was included. Again, the seeds were examined weekly for germination under a stereo microscope. Final counts of the number of germinated seeds were made after 16 days.

A third experiment repeated the two previous experiments, using the same methodology. However, one additional treatment was applied after 16 days incubation. All petri plates were moved outdoors for 24 hours, during which all plates were exposed to bright sunlight for 6 hours. The number of germinated seeds were counted on day 16 prior to sunlight exposure, and again on day 25, 8 days after exposure to sunlight.

Field Experiments

Experiments were set up examining germination of *S. atrocinctus* on peat-till berms and acid-generating tailings in field conditions in Buchans, Newfoundland. During these field trials, seed samples stored at refrigerator temperatures were used. Seeds were not scarified prior to planting, as the tailings were acid.

Till Berm Field Trial: The banks of 1 m high peat-till berms (1:1.7 slope) erected during construction of six circular ponds in 1989 remained generally devoid of vegetation three years later. The pH of this till, slurried with distilled water, is 5 to 6. A field germination trial was set up on the bank of one berm facing west, on May 30 1992.

Natural phosphate rock and Nutricote (18-18-18), a slow-release fertilizer, were applied at rates of 0.4 $kg.m^{-2}$ and 0.34 $kg.m^{-2}$ respectively to 1 m wide by 2 m long plots, each spanning from the base to the crest of the berms. Some plots received no fertilization. Control plots were parallel strips of till which did not receive chemical amendments. In total, six sets of the three treatments (control, phosphate rock, Nutricote) were set up.

Seed heads collected on October 12, 1991 were slurried with water, and approximately 40 g equivalent of dry seed was spread over each replicate of half of the treatments.

Clear plastic sheeting was placed over two of the three pairs of seeded/unseeded plots. The plastic sheeting was removed July 17, 1992, and the percent cover by plants over the top, middle and bottom of the berm spanned by each replicate was assessed on September 27, 1992.

Tailings Field Trial: The tailings, inactive since 1982, are generally devoid of a vegetation cover, except for peripheral encroaching vegetation and isolated clumps of *S. atrocinctus*. The pH of these tailings, slurried with distilled water, ranges from pH 2.7 to 5.7. Nutrients, peat and/or sawdust was applied to the tailings surface prior to seeding with *S. atrocinctus*.

On May 31, 1992, a section of the tailings surface was roughened before application of nutrients and peat or sawdust using a stiff-tined hand rake. The trial area was divided into three equal areas, and treatments were replicated within these three areas. Approximately 50 $L.m^{-2}$ of peat or sawdust were applied to the surface of 0.8 m by 3 m strips, while a third set of strips did not receive organic material.

Nutrients were the same as used for the berm experiments at application rates of 0.07 $kg.m^{-2}$ nutricote, phosphate rock (0.14 $kg.m^{-2}$) and limestone (0.07 $kg.m^{-2}$). Pairs of plots were set up perpendicular to, and over the strips with and without organic amendment.

One plot of each pair was seeded with *S. atrocinctus*, while the second plot was left unseeded. After slurrying seed heads with water, the equivalent of 25 $g.m^{-2}$ of dry seed were applied to each plot.

The percent cover by *S. atrocinctus*, moss, and a species of grass naturally colonizing the field trial was assessed on September 29, 1992.

RESULTS

Laboratory Experiments: In the first laboratory experiment, the highest percent germination was 14.6 % after 16 days incubation, in the treatment using seeds stored at -20°C and scarified for 2 minutes prior to planting (Table 1). Germination ranged from 0% to 4% in the remainder of treatments.

Scarification	Room (21C)	Fridge (8C)	**Freezer (-20C)**	28-Feb-92
0.5 min	2.1% 2 252	2.9% 1 34	1.9% 2 172	Germination No of Replicates No. of Seeds
2.0 min	4.0% 2 323	2.0% 2 187	**14.6%** 2 468	**Germination** No of Replicates No. of Seeds
5.0 min	1.1% 2 485	0.0% 2 361	0.4% 2 401	Germination No of Replicates No. of Seeds

Table 1: *Germination of Scirpus atrocinctus seeds in Laboratory Experiment 1, according to storage temperature and scarification time. Seeds collected October 12, 1991. Sulphuric acid (60%) used for scarification. Experiment performed February 12 through February 28, 1992.*

These results suggested that those seeds stored at -20°C experiment were most viable. In the second experiment, seeds stored in the freezer were used and the scarification treatment was repeated. In this experiment, the highest percent germination, 36.8 %, was recorded for the 0.5 minute scarification treatment (Table 2), in contrast with the results of the first experiment, where the highest percent germination was observed in the two minute scarification treatment. Less than 10 % of seeds germinated in the remainder of treatments. Overall, a clear relationship between time of scarification and percent germination is not apparent.

Scarification	**Freezer (-20 C)**	14-Apr-92
Control	1.5% 2 331	Germination No. of Replicates No. of Seeds
0.5 min	**36.8%** 3 361	**Germination** No. of Replicates No. of Seeds
1.0 min	9.7% 3 594	Germination No. of Replicates No. of Seeds
2.0 min	6.6% 3 814	Germination No. of Replicates No. of Seeds
5.0 min	4.8% 3 516	Germination No. of Replicates No. of Seeds

Table 2: *Germination of Scirpus atrocinctus seeds in Laboratory Experiment 2, according to storage temperature and scarification time. Seeds collected October 12, 1991. Sulphuric acid (60%) used for scarification. Experiment performed March 29 through April 14, 1992.*

The third germination experiment repeated the treatments tested in the first two experiments. After 16 days following set-up, germination in all treatments was less than 5 % (results not shown). This is in contrast with the previous two experiments, where percent germination was as high as 36.8 %.

Given these poor germination results after 16 days, a final measure was taken before abandonment of the third experiment. All plates with seeds on agar were moved outdoors on May 21, 1992, into bright sunlight and high temperatures inside the petri plates. The next morning, all petri plates were returned to the laboratory growth set-up. From examination of the plates two days later, it was apparent that, although those seedlings which had developed prior to exposure to sunlight were dead, a large percentage of the remaining seeds had germinated.

Eight days after exposure to sunlight, germination had reached as high as 89.5% in un-scarified seeds originally stored in the refrigerator (Table 3), while 87.2% (1 minute scarification) and 80.9 % (2 minute scarification) germination were observed in other treatments using the refrigerator-stored seeds.

Scarification	Room (21 C)	Fridge (8 C)	Freezer (-20 C)	29-May-92
Control	0.0% 1 145	**89.5%** 1 153	0.0% 1 99	**Germination** No. of Replicates No. of Seeds
1.0 min	71.8% 4 216	87.2% 4 187	85.3% 5 218	**Germination** No. of Replicates No. of Seeds
2.0 min	0.0% 4 146	80.9% 4 178	0.0% 4 240	**Germination** No. of Replicates No. of Seeds
5.0 min	37.1% 4 197	0.0% 5 210	10.1% 4 218	**Germination** No. of Replicates No. of Seeds

Table 3: *Germination of Scirpus atrocinctus seeds in Laboratory Experiment 3, according to storage temperature and scarification time. Seeds collected October 12, 1991. Sulphuric acid (60%) used for scarification. Experiment performed May 4 through May 29, 1992. Seeds incubated in laboratory May 4 through May 20 (germination < 5 % in all treatments). Seeds exposed to direct sunlight May 21, then returned to laboratory.*

Field Plots: Poor germination/seedling establishment was observed when *S. atrocinctus* seeds were planted directly onto the till without nutrients (Control, 1.7% to 5% cover; Table 4). Better coverage by seedlings was observed in those treatments where the till berm was amended with natural phosphate rock (8% to 30% coverage). However, the best coverage was observed in those treatments where nitrogen was supplied as well (58% to 72% coverage) through addition of Nutricote. Plants were as tall as 0.3 m.

Seeding	Natural Phosphate Rock S.atrocinctus cover *	Nutricote Slow-Release Fertilizer S. atrocinctus cover *	Control (No Amendment) S. atrocinctus cover *
Top of Berm S.atrocinctus	23.3%	66.7%	3.7%
None	0.4%	0.1%	0.0%
Middle S.atrocinctus	30.0%	58.3%	5.0%
None	1.7%	1.3%	0.0%
Bottom of Berm S.atrocinctus	8.3%	71.7%	1.7%
None	1.7%	18.3%	0.0%
* Number of Replicates = 3			

Table 4: *Percentage cover by Scirpus atrocinctus in seeded and unseeded plots on till berm amended with natural phosphate rock or Nutricote slow release fertilizer, September 28, 1992, 121 days following seeding.*

The control plots (no seeding, no amendments) remained bare as expected. Addition of phosphate rock and Nutricote promoted the development of *S. atrocinctus* seedlings. In unseeded treatments with phosphate rock, coverage by seedlings ranged from 0.4% to 1.7%. In the unseeded plots with Nutricote, coverage by seedlings ranged from 0.1% to 18.3%.

Overall, in the tailings plot, poor development of *S. atrocinctus*, moss and any other species was observed in all treatments. There was no *S. atrocinctus*, moss, or other species growing on plots which received natural phosphate rock alone or limestone alone, with or without sawdust or peat.

However, in treatments receiving Nutricote, or Nutricote plus limestone, small patches of moss protonema developed, covering 0.1% to 5% of the plots. As well, seedlings of an unidentified grass had established, especially in those plots where sawdust or peat was added. *S. atrocinctus* plants were not observed in any of the treatments where Nutricote alone was added to bare tailings, or to tailings where peat or sawdust were added (Table 5). When both phosphate rock and nutricote was applied, *S. atrocinctus* was present.

The addition of both Nutricote and natural phosphate rock, combined with sawdust or peat amendments, appears to have provided conditions, at some spots within these treatments, where *S. atrocinctus* seeds could germinate and seedlings could develop (Table 5). These plots also supported greater moss development and the same species of grass which had invaded the other plots. However, coverage by *S. atrocinctus* seedlings was relatively low (2.5 %) within these plots, compared to the results of till berm field trial.

ORGANIC AMENDMENT		CHEMICAL AMENDMENT ***								
		Nutricote Slow-Release Fertilizer			Limestone + Nutricote			Phosphate Rock + Nutricote		
		% Cover			% Cover			% Cover		
	Seeding	S.a*	Moss	Grass **	S.a.	Moss	Grass **	S.a.	Moss	Grass **
Control	S.a.*	0	1.0	0	0	0.1	1	0	3	1
	None	0	3.7	0	0	5.0	0	0	10	0
Peat	S.a.*	0	0.1	1	0	0.5	1	2.5	1	1
	None	0	0.5	0	0	0.1	0	0	10	0
Sawdust	S.a.*	0	0.1	1	0	0.1	1	2.5	0.5	1
	None	0	0.5	0	0	0	1	0	1	1

* Scirpus atrocinctus
** Single grass species
*** Control, Natural Phosphate Rock, Limestone treatment results all zero; results not shown.

Table 5: *Percentage cover by S. atrocinctus, moss and a grass species in seeded and unseeded plots on acidic tailings with chemical and/or organic amendments, September 29, 1992, 122 days following seeding.*

Discussion and Conclusions

The results of the third laboratory experiment, where a high percentage of seeds germinated only two days following exposure to bright sunlight, clearly indicate that high or variable light and/or temperature is (are) necessary for triggering germination of *Scirpus atrocinctus* seeds.

In light of these results, variation within and between the first, second and third laboratory experiments may have been due to subtle differences (unrecorded) in levels or fluctuations of temperature and/or light during the incubation periods under fluorescent lighting. Given the high percent germination in the control treatment in the third lab experiment, scarification using concentrated sulphuric acid appears unnecessary for seed germination. Storage temperature of the seeds is also not important. Similar results for species closely related to *S. atrocinctus* have been observed by other workers. Pons and Schroder (1986) observed that the germination of seeds of *Scirpus juncoides* required temperature fluctuations, and that oxygen concentrations greater that 10% suppress germination.

Overall, the results of the laboratory experiments indicate that a high percentage (90%) of *S. atrocinctus* seeds collected in the fall can be viable, and will germinate if the correct conditions for germination are provided. High or fluctuating light and/or temperature can, in fact, be expected at the surface of bare till berms or tailings. Second, up to 37 % of seeds remained viable following exposure to concentrated sulphuric acid for 5 minutes, and following incubation on agar wetted with low pH rinse water. Therefore, it is feasible that *S. atrocinctus* seeds would germinate and seedlings develop in acidic conditions such as on acidic tailings beaches.

The results of the field trials reflect the relative effectiveness of the various treatments in supporting seedling establishment. Given the rapid development of *S. atrocinctus* cover on the till berms with the addition of seeds and slow release fertilizer, it appears that a simple technique for revegetating disturbed soils using an endemic species has been developed. This technique should serve as an effective tool for permanently stabilizing disturbed areas against erosion, particularly in areas inaccessible by heavy machinery.

The field trials on the tailings indicate that supplying seeds alone is inadequate to initiate colonization. Organic amendments, available nitrogen and, possibly, surface tailings neutralization, must be supplied for *S. atrocinctus* seedling survival. While limestone addition did not provide appropriate conditions for seedling survival, natural phosphate rock addition did. Phosphate rock probably served as a slow release neutralizing agent, while the reactions between limestone and acidic tailings likely occur only in the short term.

While a good vegetation cover was not achieved in any of the treatments applied to the tailings surface, the results of the Nutricote-phosphate rock-organic amendment treatments are encouraging. Promotion of moss cover development, through supplying available nitrogen and phosphate as phosphate rock may find applications in certain conditions.

Acknowledgements

We wish to express our appreciation to George Neary for his encouragement of new approaches, and his enthusiasm to work cooperatively in all aspects. We thank ASARCO for its continued support of the project in Buchans, Newfoundland.

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SESSION V: SHORELINE AND AQUATIC REHABILITATION

REVIEW OF SOIL BIOENGINEERING TECHNIQUES IN STREAM REHABILITATION

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ABSTRACT

Increased consideration of the ecological health and stability of streams is causing design professionals to pay closer attention to the low flow channel of a stream and it's relation to it's floodplain. Traditional methods of erosion control are designed to withstand the maximum force of water applied to them and to fix the location and elevation of the channel permanently and thus eliminate the natural migration and sculpting of the natural channel. Soil bioengineering offers an erosion control alternative which consolidates and reinforces the soil through a vigorous root system while resisting the erosive forces of flood water by increasing roughness adjacent to the soil surface. Techniques such as live cribwalls, fascines, brush layers, brush mattresses, and live stakes used alone or in combination to control erosion naturally without restricting the natural movement of the stream bed.

The Rosgen Classification of the fluvial geomorphology of natural channels allows for the re-establishment of a natural stable meander sequence and profile in unstable and degraded streams and the appropriate habitat to support a healthy native aquatic ecosystem.

Together soil bioengineering and fluvial geomorphology allow designers to re-establish healthy and natural low flow channels in highly degraded streams. Examples of these restorations include Sheridan Creek, Schneider Creek and Groff Mill Creek, all of which will be discussed in this presentation.

CASE STUDIES IN SHORELINE REGENERATION

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Introduction

A number of human activities can cause destruction of natural vegetation and habitat structure along shorelines of lakes and rivers. These activities include urban stormwater control (channelization of creeks), infilling of lake shoreline areas for creation of parks, streambank alterations at pipeline and road crossings to name only a few.

In addition to reducing erosion and thus, protecting water quality, shoreline rehabilitation and regeneration also increases habitat diversity for both aquatic and terrestrial wildlife and improves overall aesthetics; however, the definition of 'aesthetically pleasing' is quite subjective. For example in urban settings, people like to 'see' the creek or pond, therefore manicured lawns often dominate the shorelines and stream banks. Natural trees and shrubs which provide natural bank stability are often removed. For flood control in urban areas, streams are engineered and often appear as concrete channels or gabion-lined watercourses. From a biological perspective, none of the above conditions are particularly productive and habitat diversity is low.

In the following case studies, natural shorelines have been negatively impacted by human activity and rehabilitation options have been presented or implemented. These areas were selected as they include a variety of problem types, habitat types, and regeneration plans.

Case Study No. 1 Kapuskasing River

This case study describes some of the effects of log drives on the Kapuskasing River in northern Ontario and discusses the recommendations for rehabilitation of affected areas. The Kapuskasing River flows into the Moose River and subsequently in to Hudson Bay and has been used for logging since 1922. Due to environmental concerns, log driving is being phased out and has been virtually eliminated in Canada except in BC and the east coast. Next year will be the last year of log driving on the Kapuskasing River.

Trees are cut in winter, transported to the river's edge and piled on shore or pushed onto the ice to wait for spring break-up. The area where logs are delivered to the river are referred to as 'landings'. These landings can be up to 100-200m wide and 4km long. In spring, the logs are floated down river to the Spruce Falls mill.

As a result of log storage and the use of heavy equipment on the river banks, the landings have been stripped of vegetation and severe erosion (rutting) is occurring in some areas. ESP's study determined that approximately 20km of river shoreline are in this condition. Due to lack of vegetation, erosion and slumping of the river banks is occurring and substantial sediment movement into the water is visible following heavy rainfalls.

In addition to loss of vegetation, large quantities of branches, bark chips, etc. accumulate each year at the landings. This material is pushed back from the river's edge and the debris piles are up to 40' high covering vegetation and soils. The surface of these areas is extremely uneven due to erosion gullies and the height of the piles. Some attempts have been made to plant small trees on this material but it is a poor growing medium and there has been limited success.

Not surprisingly, the river banks at the landing areas are significantly different from the undisturbed shoreline areas.

Natural diversity of shoreline has been lost, resulting in loss of both aquatic and terrestrial wildlife habitats. Grasses are re-establishing on landings that have not been used for several years, indicating that natural regeneration is possible, however, it is a very slow process.

Each landing area was surveyed in detail and specific rehabilitation plans were developed with a goal of bank stabilization to reduce sedimentation and increase fish and wildlife habitat diversity. Much of the rehabilitation will consist of grading, fertilizing, mulching, seeding, and tree planting.

Deep erosion gullies should be graded to allow establishment of seed and planted trees. The bottom of these areas can be lined with a single layer of rock rip-rap to reduced erosion potential and if extended into the water, increase aquatic habitat diversity and availability. Bank erosion and slumping has reduced fish habitat in the littoral zone at the landings. Habitat enhancement can be achieved through the creation of submerged rocky shoals or the construction of small rock groynes to create quiet backwater areas, providing cover and nursery habitat.

The recommendations for regeneration of the landings have been accepted, however, implementation of these plans will not commence until after log driving on the Kap River ceases.

Case Study No. 2 Kempenfelt Bay

ESP conducted a fish habitat study for the City of Barrie to identify existing fish habitat and areas for potential habitat enhancement. Kempenfelt Bay historically supported a very healthy coldwater fishery of lake trout and whitefish. These populations have been reduced through deterioration of water quality due to eutrophication.

The bay also supported warmwater species including northern pike, largemouth bass and muskellunge. These populations have largely been reduced due to habitat destruction including infilling of wetlands and shoreline alterations. The study concluded that man-made structures (i.e. breakwalls) make up 58% of the City's waterfront. As a result, the shoreline is very straight and sterile in many areas, resulting in a very 'hard' shoreline and a general lack of overhead cover and shoreline diversity.

There are areas where the shoreline vegetation is still present, however, in some areas local residents have removed trees along an embankment to maintain their view of the lake. This has resulted in bank erosion, loss of soil and sedimentation into fish habitat.

Natural shorelines are quite irregular with small bays, rocks and overhanging vegetation. There are still some areas like this along the city's shoreline. ESP developed concept plans that can be applied to existing "sterile" shoreline or can be used to enhance fish habitat if shoreline alterations are necessary during new development projects. The plans provide a more natural-looking shoreline and enhance fish habitat through increased diversity. There are some large undeveloped tracts of property where we proposed that shoreline habitat enhancement be integrated into future development.

To create more natural attributes creation of small peninsulas and embayments and tree-planting at the waters edge was recommended. These features are created through dredging and filling, ultimately look more natural and enhances fish habitat. The lee side of peninsulas would provide protected areas for species such as northern pike and minnows and nursery habitat for a number of fish species. The windward side could be constructed of rock rubble which would provide smallmouth bass habitat and potential lake trout spawning habitat. Currently, the only lake trout spawning that occurs in Kempenfelt Bay takes place on the marina breakwall.

Submergent rock "islands" placed offshore will provide underwater structure, attracting smallmouth bass and other species. The specific design of these concepts must consider local flow patterns and wave action prior to detailed design and construction.

The base of these structures would be made of large rock which would be capped with soil. Grasses, shrubs and trees would be planted which will eventually stabilize the soil and provide shade and cover to fish species, utilizing the lake's littoral zone. Similar structures have been constructed in Thunder Bay Harbour.

These concepts have been presented to the City of Barrie and Ontario Ministry of Natural Resources where they were received with interest and enthusiasm. Final approval and implementation is dependent on future development plans and municipal budgets.

Case Study No. 3 Parliament Hill

In 1983, ESP prepared a plan to stabilize the steep slope at Parliament Hill on the Ottawa River. ESP provided alternatives for slope rehabilitation and gave detailed solutions for management with vegetation using native species. ESP conducted an inventory of slope conditions, mapped soil types, erosional features, and conditions of existing vegetation and prepared a plan for stabilization and rehabilitation of the slope. The bank was very unstable with obvious soil erosion and continual loss of vegetative cover.

The presence of fallen structures, debris and garbage added to the unsightly appearance of the slope and regeneration was not occurring due to lack of leaf litter accumulation, poor species diversity, and continued pedestrian access. The master rehabilitation plan outlined detailed recommendations for vegetation establishment involving planting of deep-rooted native trees, shrubs and ground covers using specialized planting techniques designed for steep and unstable slopes. One of the key aspects of the re-vegetation plan was the use of only indigenous plant species.

The benefits of vegetation management include:

- deep-rooted plants stabilize upper layers of soil;
- diverse ground cover protects soil from erosion; and
- species diversity assures long term stability and aesthetic appeal.

The slope was divided into management areas depending on specific problems and conditions. Log grating was constructed on the steepest slopes, while fascines, terraces and stop logs were some of the techniques used elsewhere on the slope. The log grid (grating) was secured to the slope using live pegs, 60 cm long. The grating was filled with topsoil, seeded, and trees and shrubs were planted.

The project was successful resulting in a stable bank increased species diversity and natural regeneration.

Summary

Revised approaches to development and available rehabilitation techniques and materials can be used to successfully regenerate degraded shoreline areas while at the same time, protecting water quality and enhancing habitat for fish and wildlife.

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ALTERNATIVES FOR INTEGRATED NATURAL VALLEY DESIGN

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ABSTRACT

Over the past 200 years land use and water management practices have degraded the resilience, productive capacity and stability of our ecosystems. Reduced diversity and habitat connectivity now jeopardize the ecosystem integrity of watersheds and valley systems. Attempts to respond have generally promoted further degradation by decoupling linkages, treating symptoms instead of causes, and isolating habitat fragments.

We have designed rehabilitation plans for whole valley systems as well as for specific sites within a valley context. Ecosystem potential is determined from the perspective of an integrated mosaic of habitats and ecotones needed to function at a sustainable, productive level. Linear and lateral habitat gradients are re-established by designing a stable, geomorphologic configuration for channels, functional floodplain elevations, transition habitats such as floodplain pools, links to upland habitats, and riparian corridors.

Detailed habitat requirements for representative species or species guilds are considered for type and size of homogeneous habitat zones, necessary adjacent habitats, configuration of connecting corridors and specific habitat structure. Water management, soil conservation, and human land use criteria are integrated with the rehabilitation plans to achieve viable, useful and attractive landscapes which meet the rehabilitation targets.